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Nuclear Power

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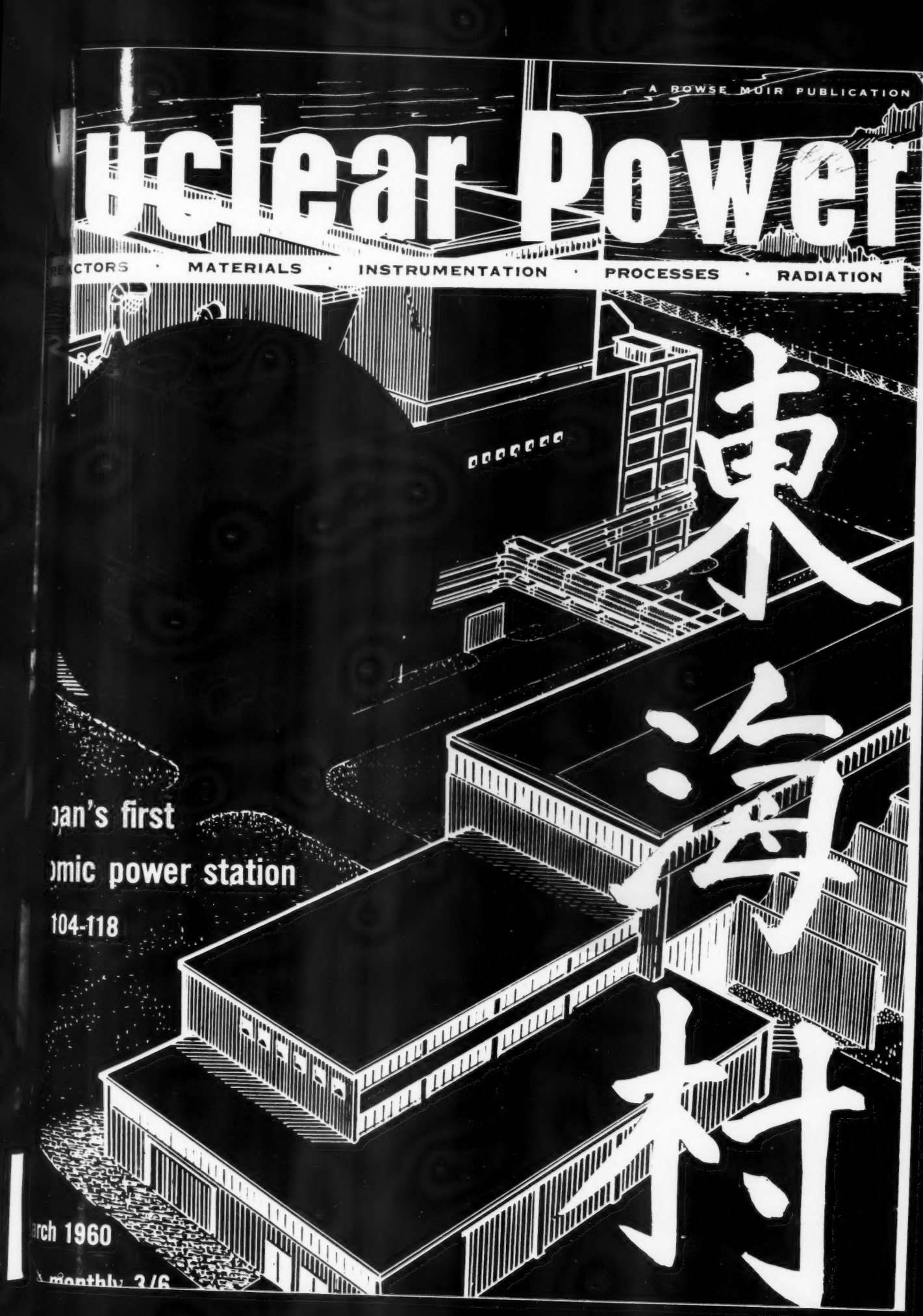

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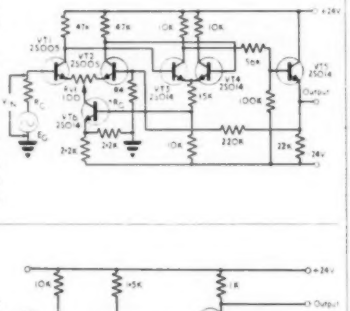
Change of output voltage referred to input for simultaneous or independent changes of supply voltages by ±1 volt	4mV
Required source impedance ...	10 kΩ
Input impedance	25 kΩ
Common mode rejection ratio ..	50,000



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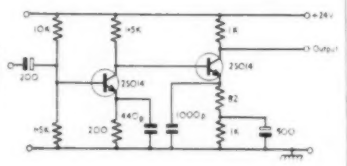

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VOL 5 NO 47 MARCH 1960

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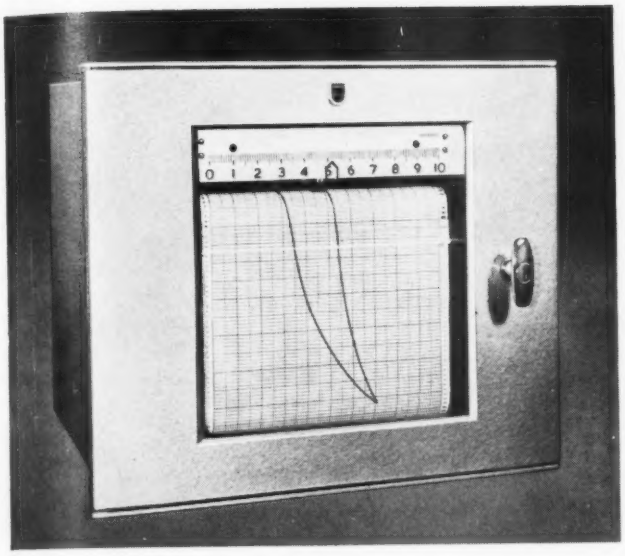

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0..... 10 mV	
0..... 20 mV	0..... 20 mV
0..... 50 mV	0..... 50 mV
0.....100 mV	0.....100 mV
0.....200 mV	0.....200 mV
0.....500 mV	0.....500 mV

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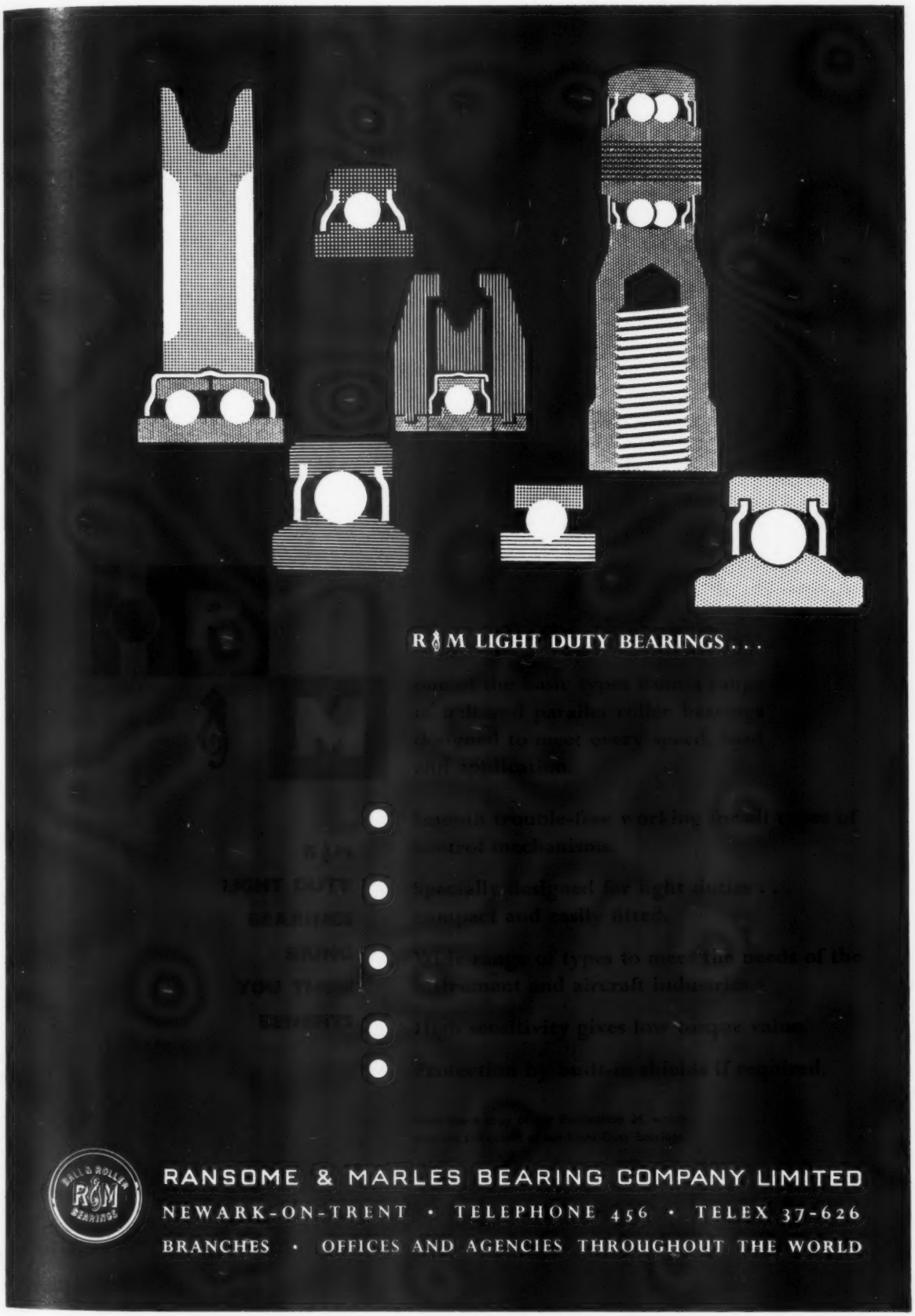
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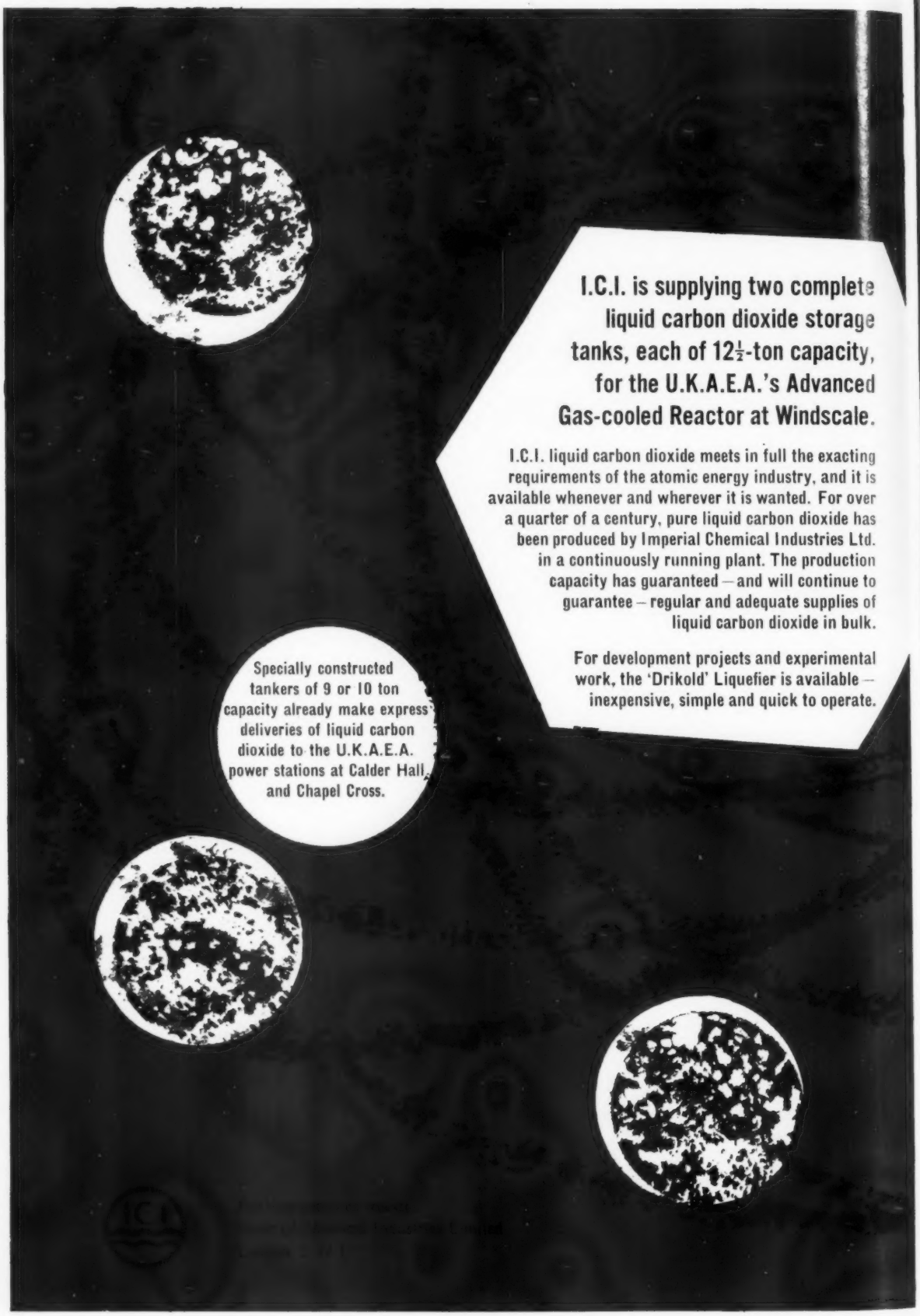
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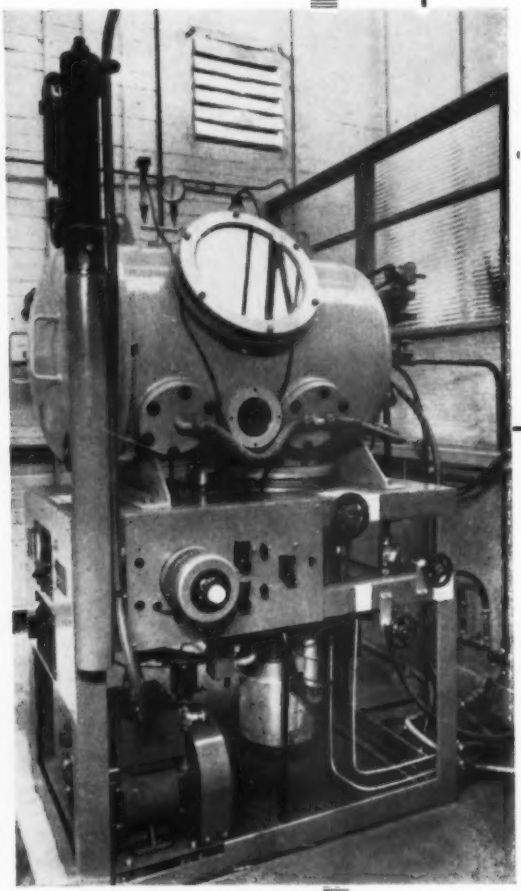

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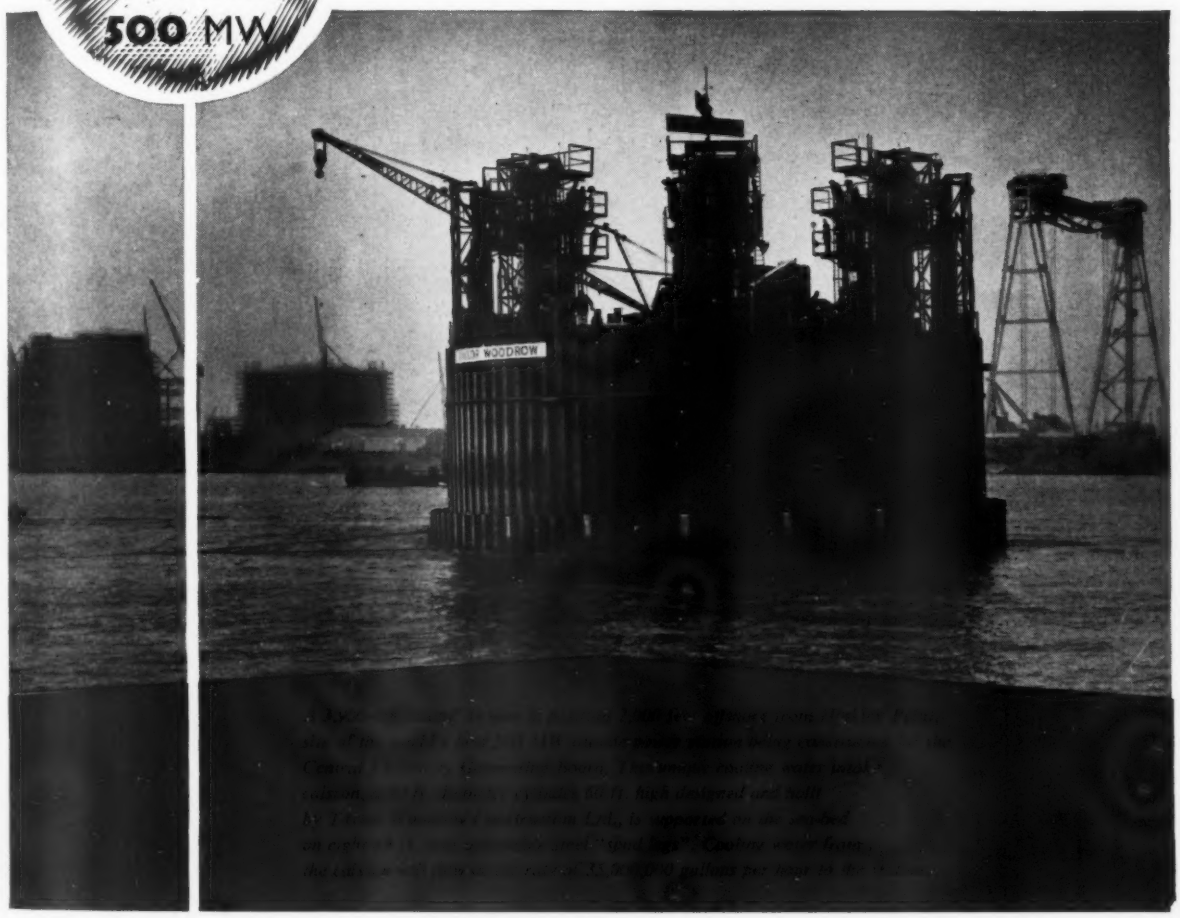

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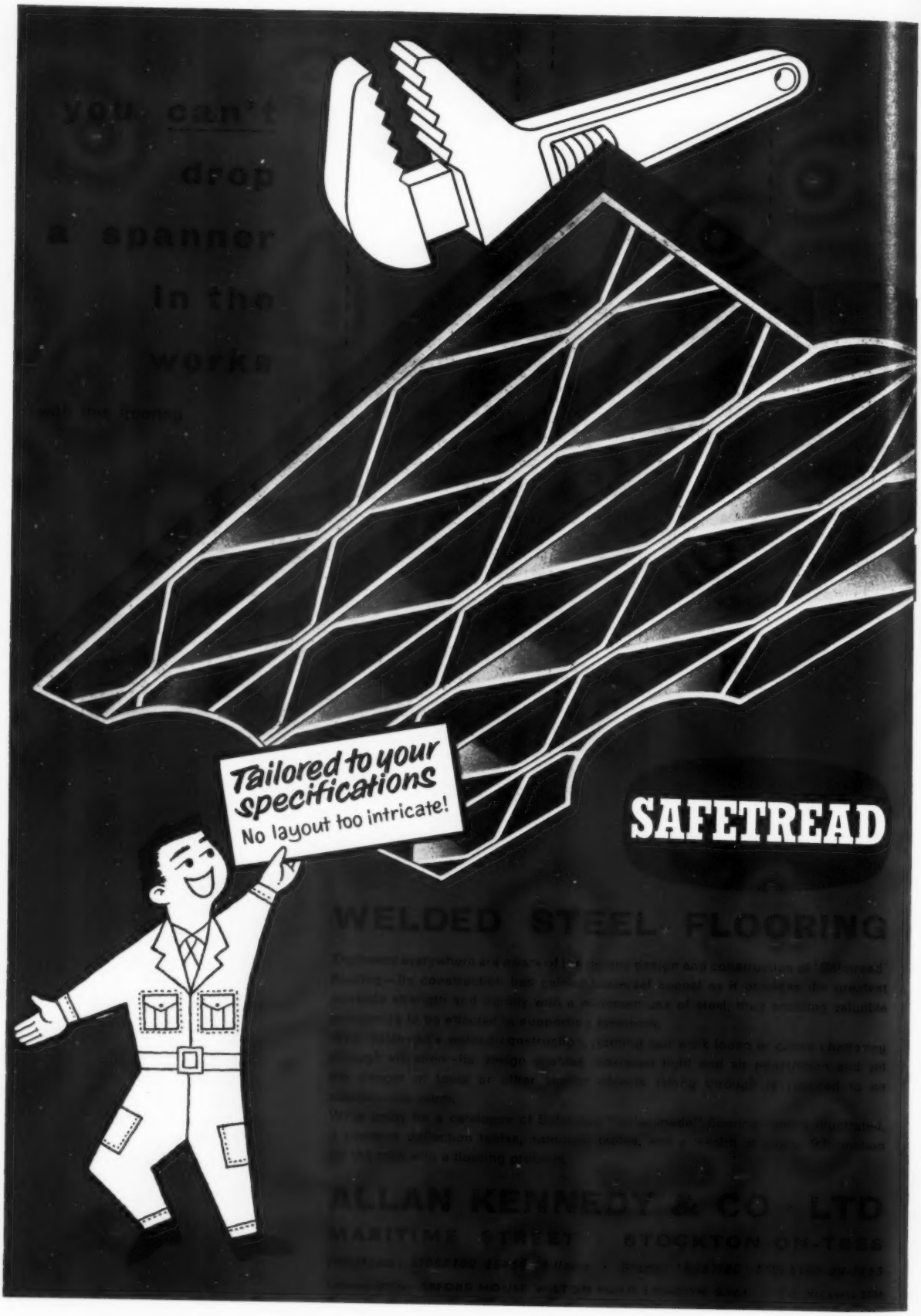

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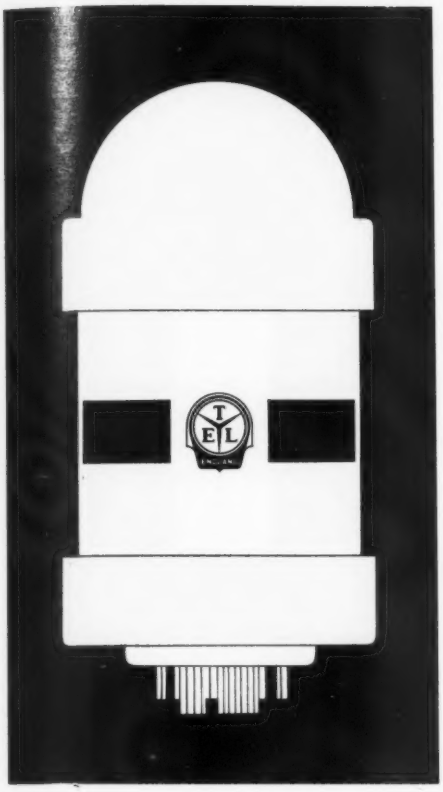

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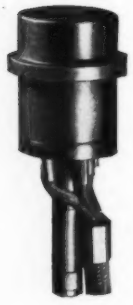

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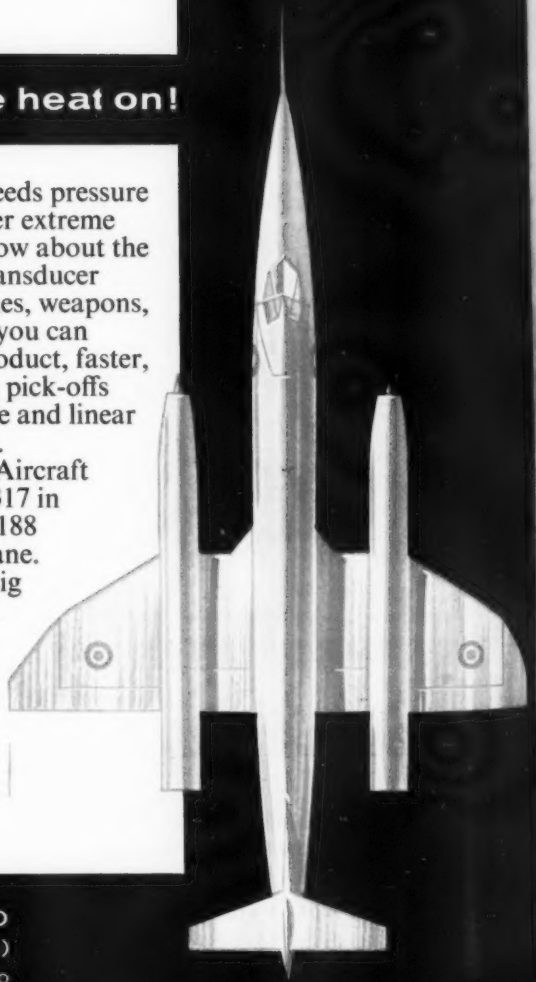

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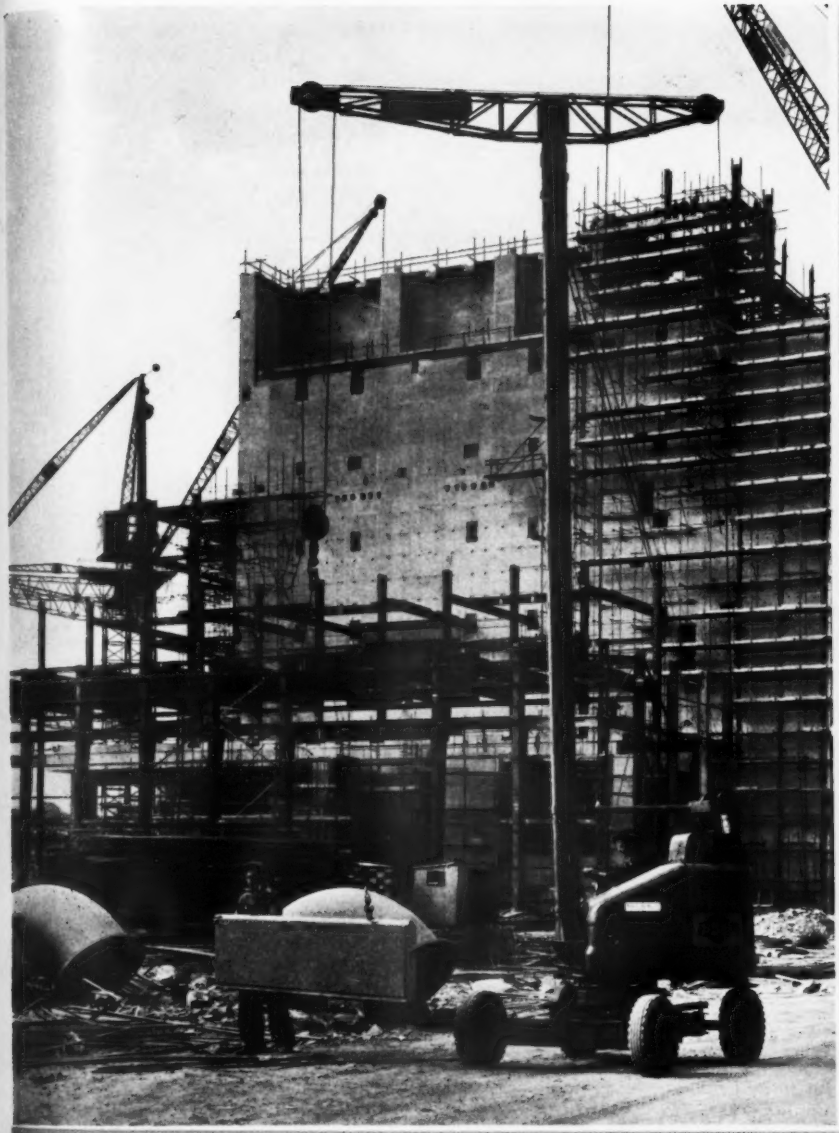

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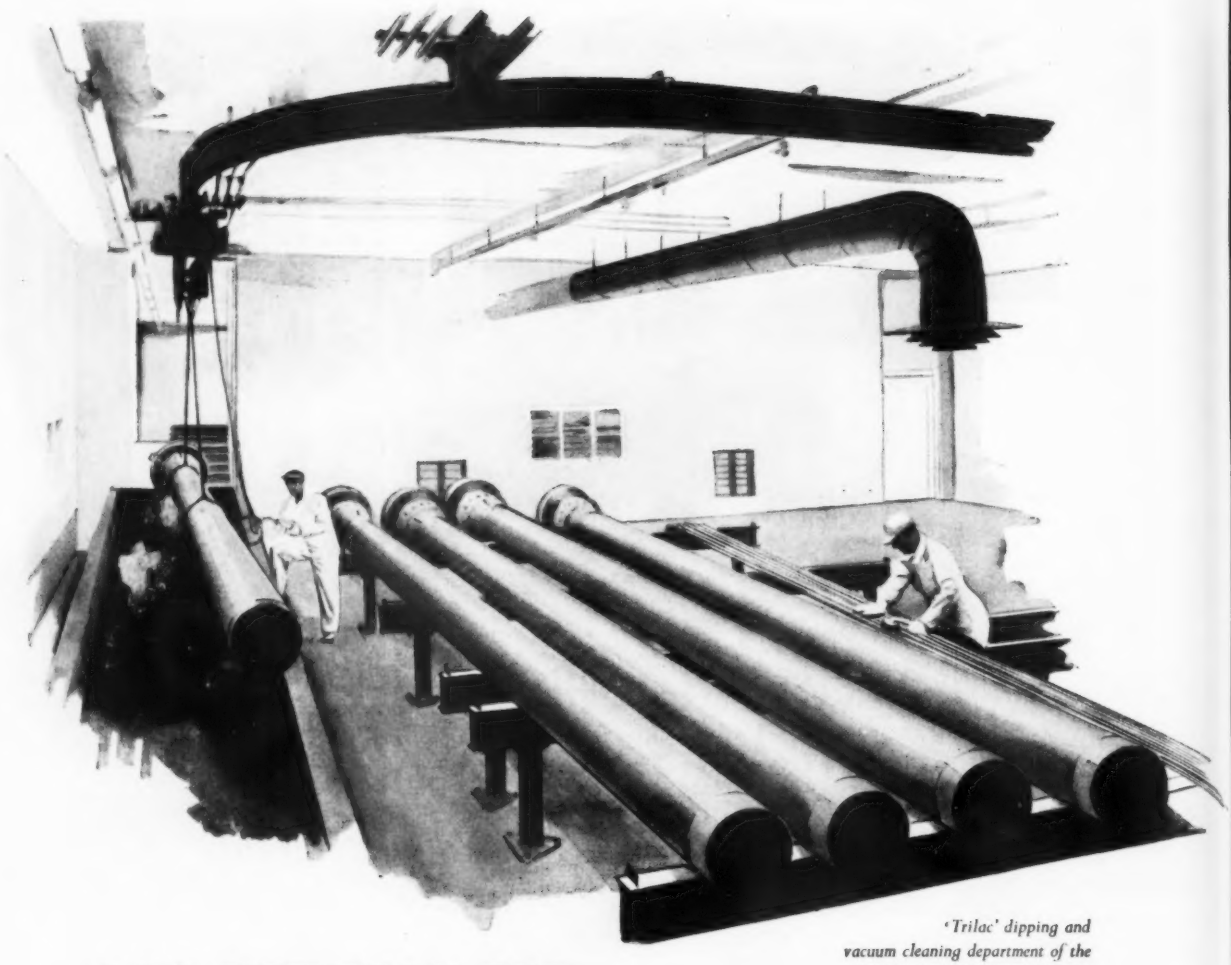

'Trilac' dipping and vacuum cleaning department of the 'CLEAN CONDITIONS' PLANT

S & L PIPEWORK FOR BRITAIN'S NUCLEAR POWER STATIONS

It is becoming general for many components for nuclear plants and other forms of construction to be assembled under entirely dust free conditions.

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An example of the work assembled in this shop is the control rod standpipes for Hunterston nuclear power station. The standpipes shown in the illustrations accommodate boron rods and house the small bore burst slug detection piping.

S & L will be pleased to discuss any problems associated with clean conditioning of industrial components.

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stainless steel submerged-arc welding flux

The new "Muraflux S.1" granular flux has been specially developed for the automatic welding of stainless steel by the submerged-arc process. The flux is designed for the welding of 18/8 chromium-nickel steels and for use with Murex "Murawire S.W.1" or "Murawire S.W.2" filler wires.

This new Murex flux is suitable for either the single-pass or multi-pass submerged-arc welding of various joints in stainless steel in the flat position and welds of excellent appearance can be produced. A high radiographic standard can be obtained and the welds have good mechanical properties. High impact properties at low temperatures can also be obtained, an important feature in fabrications for sub-zero service.

When used with "Murawire S.W.2", the flux will produce a stabilised deposit and can therefore be used for applications of the 18/8 chromium-nickel steels such as fractionating columns, storage tanks, food vessels and pipe work where resistance to weld decay is essential.

Full details of Murex "Muraflux S.1" submerged-arc welding flux will be supplied on request.

MUREX

A complete service for automatic welding

MUREX WELDING PROCESSES LIMITED, Waltham Cross, Herts.

T33

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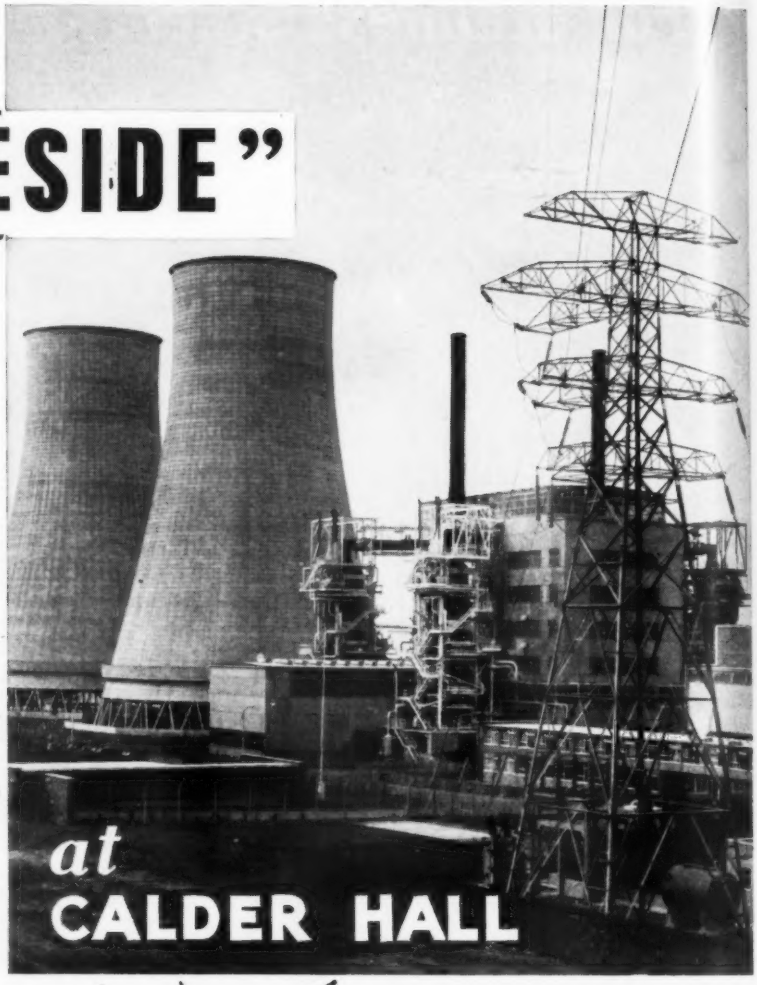

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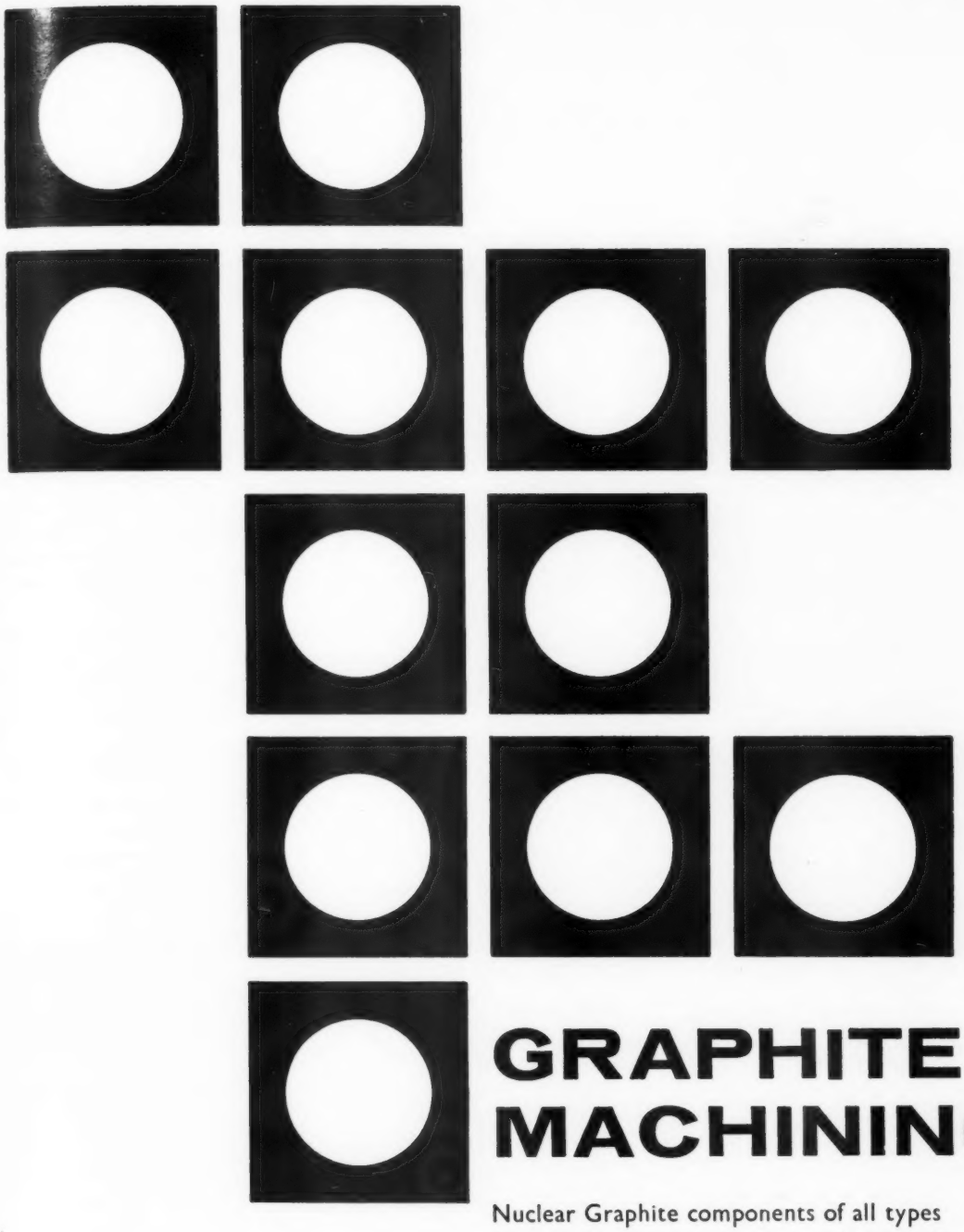

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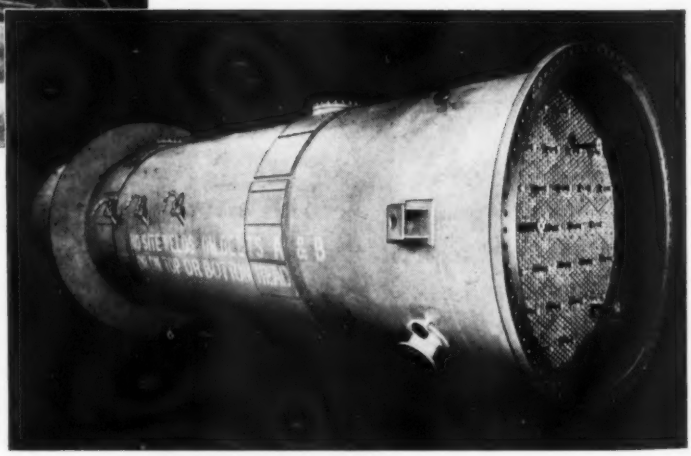
Left: A mild steel jacketed Autoclave to Class 1 construction with electrically driven stirring gear.

Below: This Ethylene Oxide Reactor weighs 135 tons, is 9 ft. 6 ins. in diameter and contains over 15 miles of 1¼ in. dia. catalyst tube.



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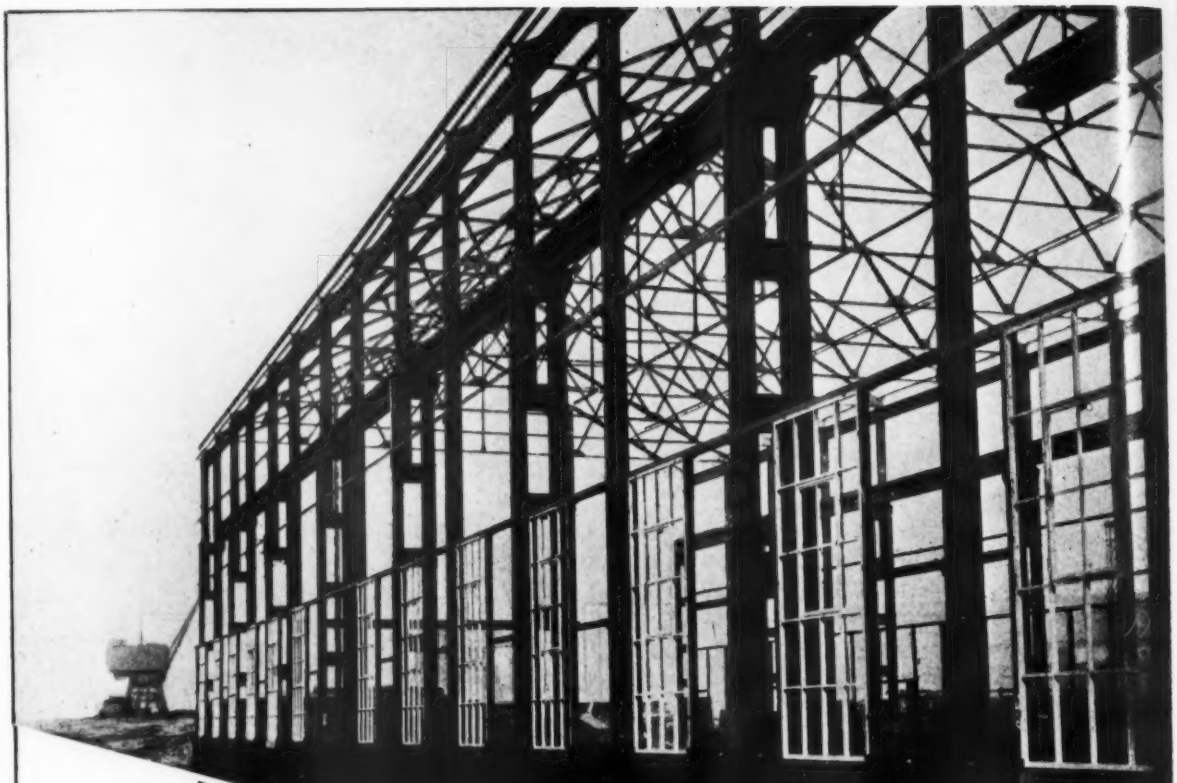
A pre-paid subscription card is provided facing page 86.



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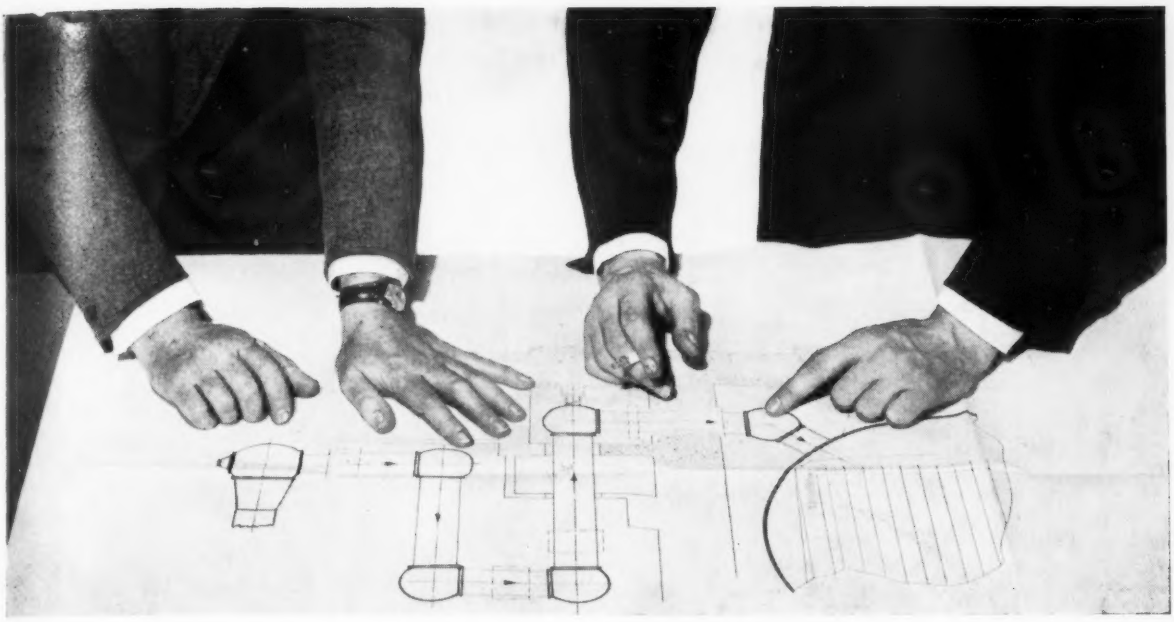

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We spread out the drawings . . . an instant of surprised silence; then that gratifying sound. It is usually something like "Of course! Why didn't somebody think of that before."

Why not indeed? All we have done is to make the bends in the CO_2 pipework of an atomic reactor, spherical. Any schoolboy with G.C.E. physics knows the formula for the thickness of a pressure vessel—

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A simple and indeed an obvious idea; but it can save large sums of money on the cost of a power station or a wind tunnel. The fact is it is not easy to see the obvious; the orthodox approach, the standard answer, get in the way. However, some of our engineers seem to be able to do it, thank goodness.

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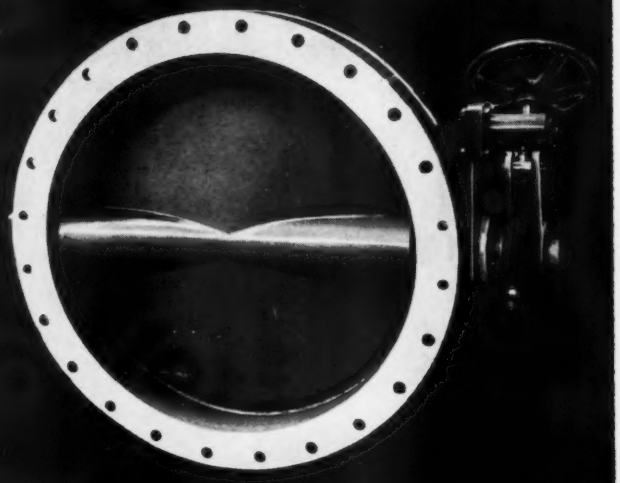
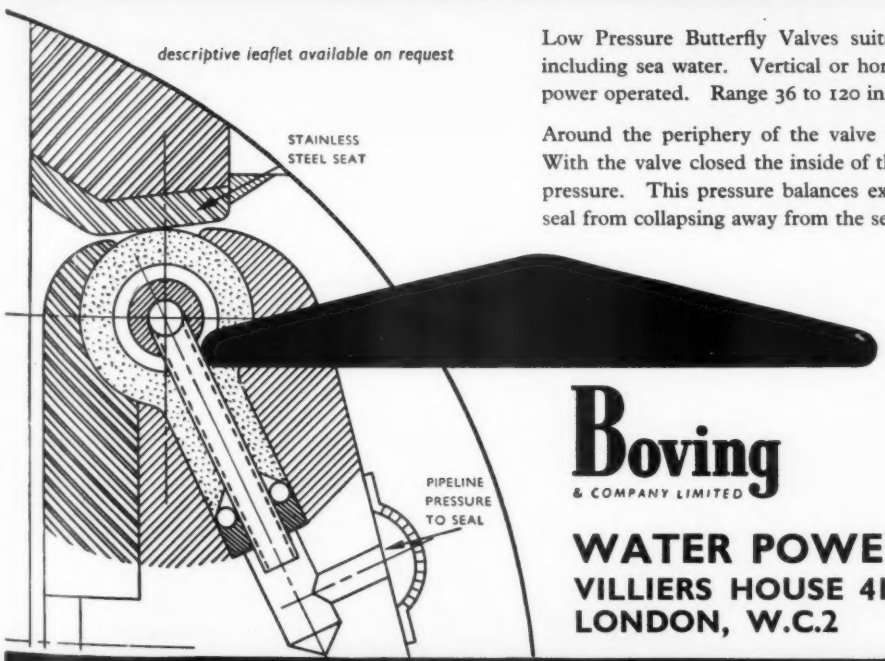


descriptive leaflet available on request



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S4

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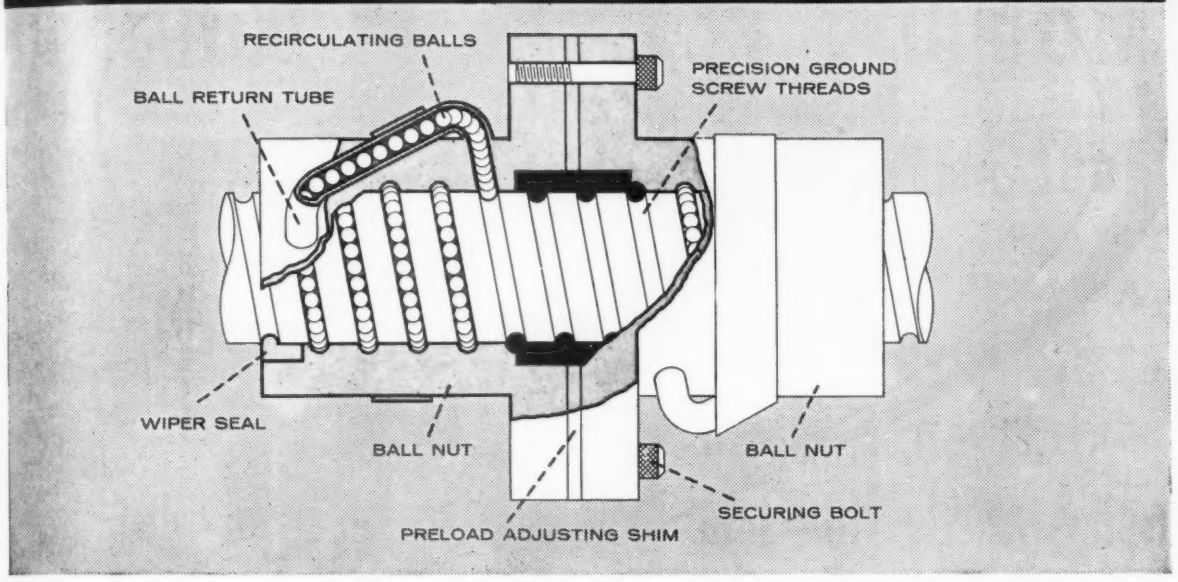
Beaver pre-loaded ball screws, up to 95% efficient, operate at -52°C to over 400°C with no backlash...



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Bristol Siddeley engineers make an exhaustive analysis of each specification. And each unit is specially designed for its particular application. Beaver ball screws are made automatically reversible or with controlled "no-back," with multiple or single circuits. Beaver pre-loaded ball screws have been proved as the most efficient method of converting rotary into linear thrust in over 2,700 engineering applications in many branches of industry. They have been designed already with rated operating load capacities of 370,000 lb (825,000 lb maximum static load) but the maximum potential operating load is, in most cases, limited only by the requirement.

Bristol Siddeley Beaver ball splines have been developed to eliminate the disadvantages of conventional splines. The designs are very effective in minimising friction, particularly when high torsional and bending loads are imposed during linear movement.

** Complete technical and manufacturing co-operation with Beaver Precision Products Inc., Detroit.*

For further information please write to J. B. Starky, Sales Manager (Beaver Products Division), Bristol Siddeley Engines Limited, PO Box 17, Coventry, England.

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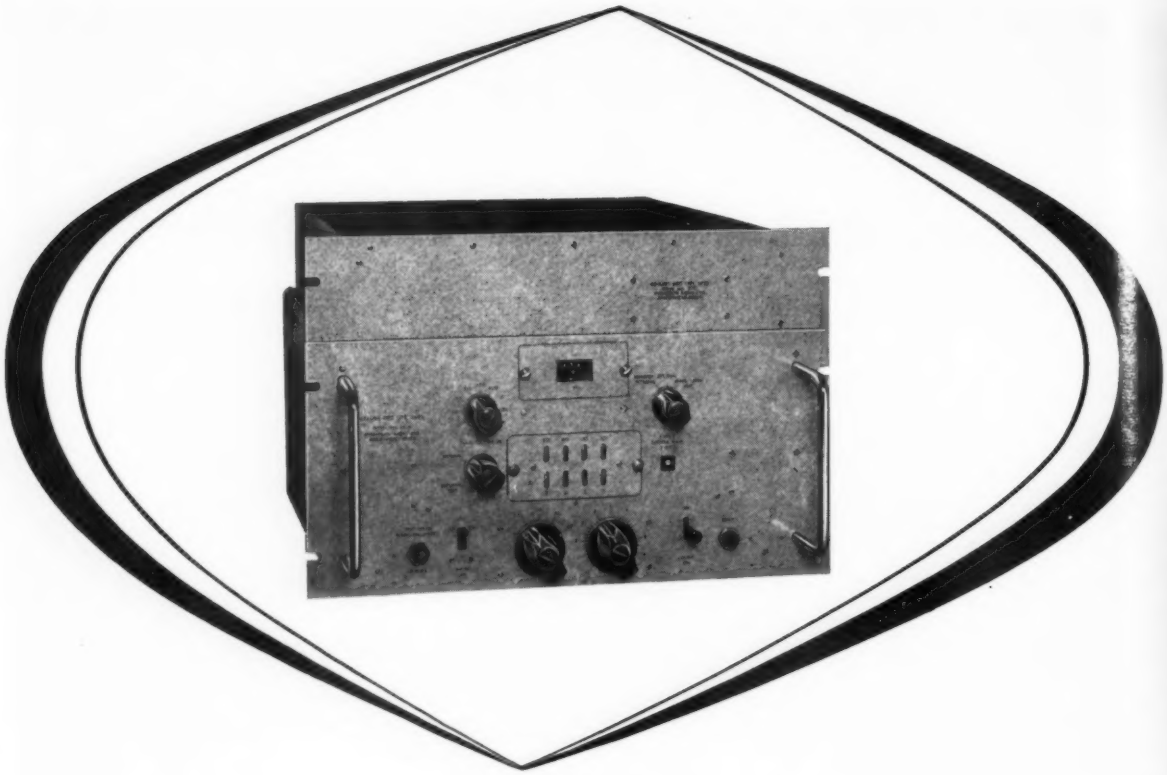

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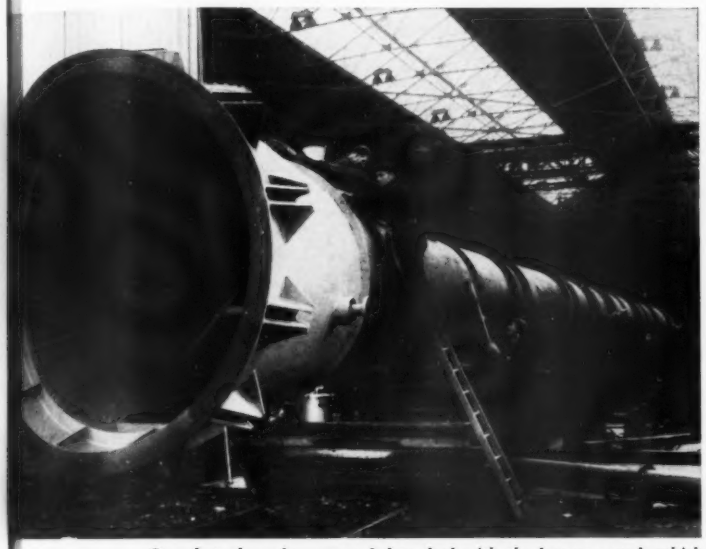

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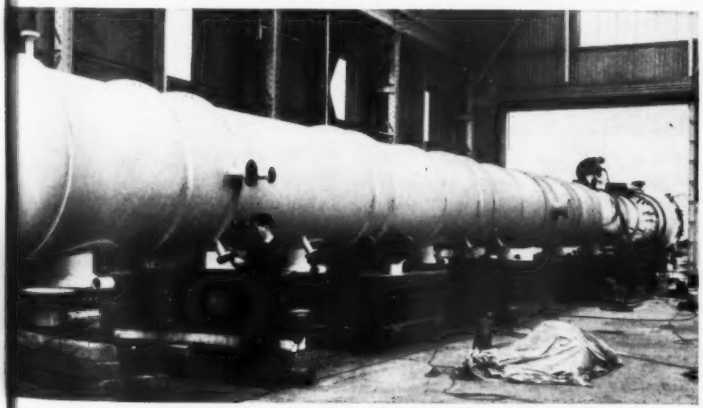

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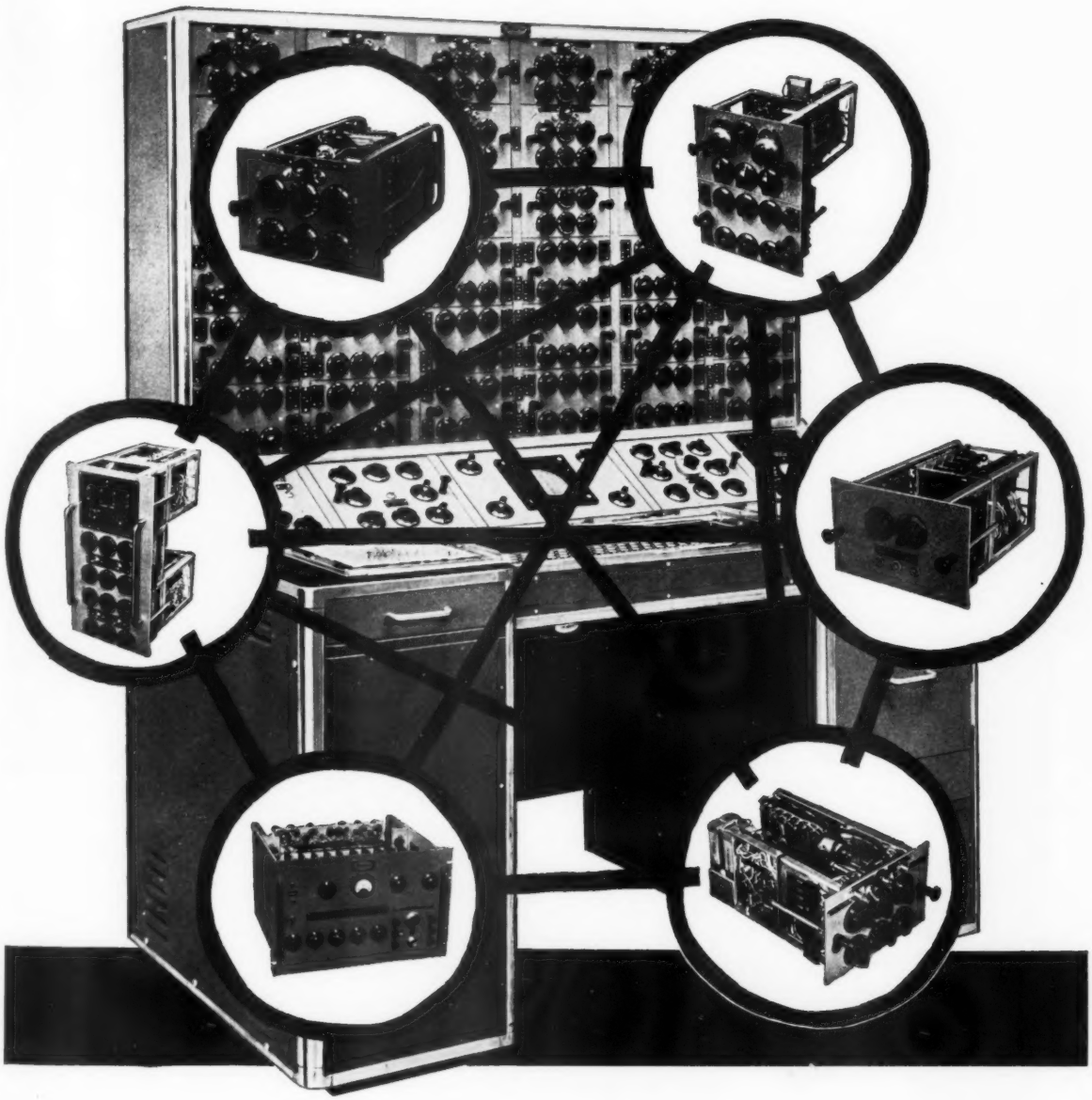

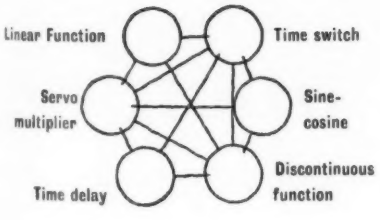

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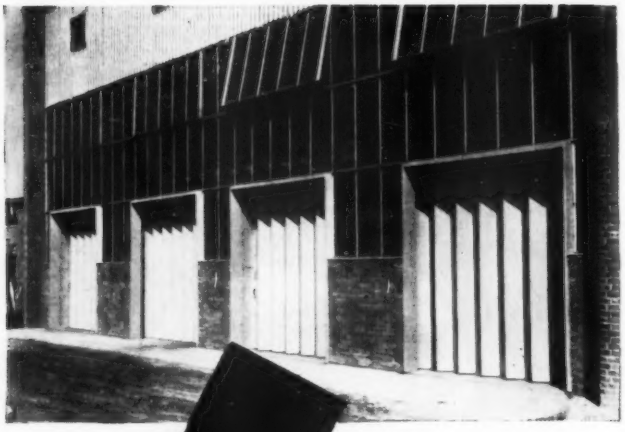

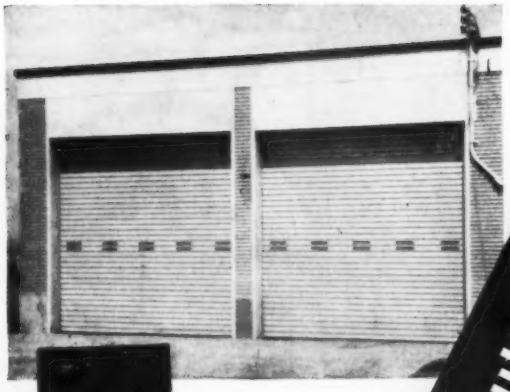

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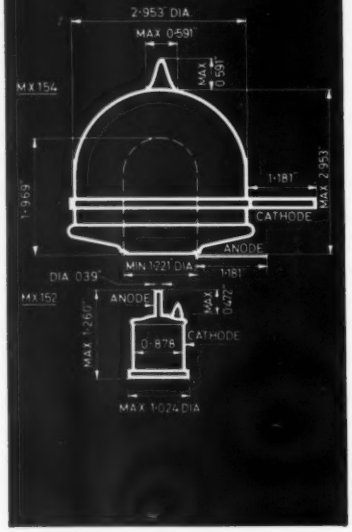

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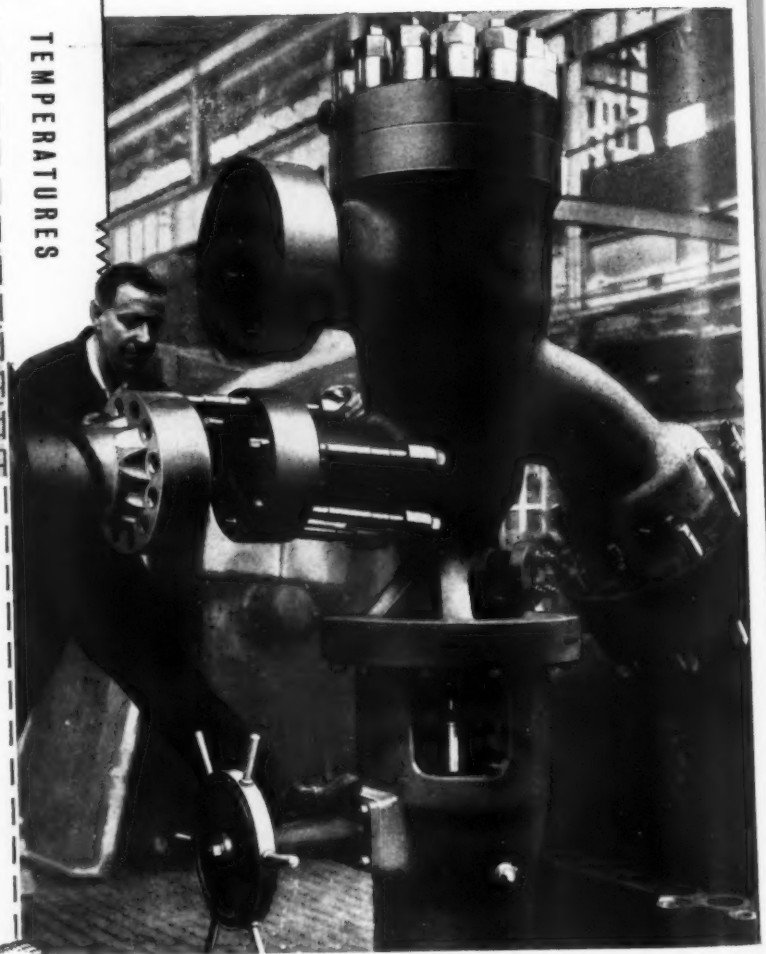

Firth Brown have developed several steels, notably Firth Brown "CRM2", Firth Brown "MOVA (2)" and Firth Brown "CHROMVA-W", which are suitable for stress parts such as bolts and studs which have to operate at elevated temperatures for long periods of time. CRM2 is designed to meet a certain level of creep-resistance together with ability to develop a high tensile strength and a good resistance to embrittlement during service. Full particulars of the Firth Brown steels in this range are in Publication No 226 which is available at once upon request.

Special bolts made in CHROMVA-W Steel used on a stop valve for a high pressure steam turbine. Initial temperature 1050°F. at 1500 lbs. per square inch.

Photograph by courtesy of A.E.I. Ltd., Turbine-Generator Division, Rugby.

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(Main Contractors: Messrs. Constructors John Brown)

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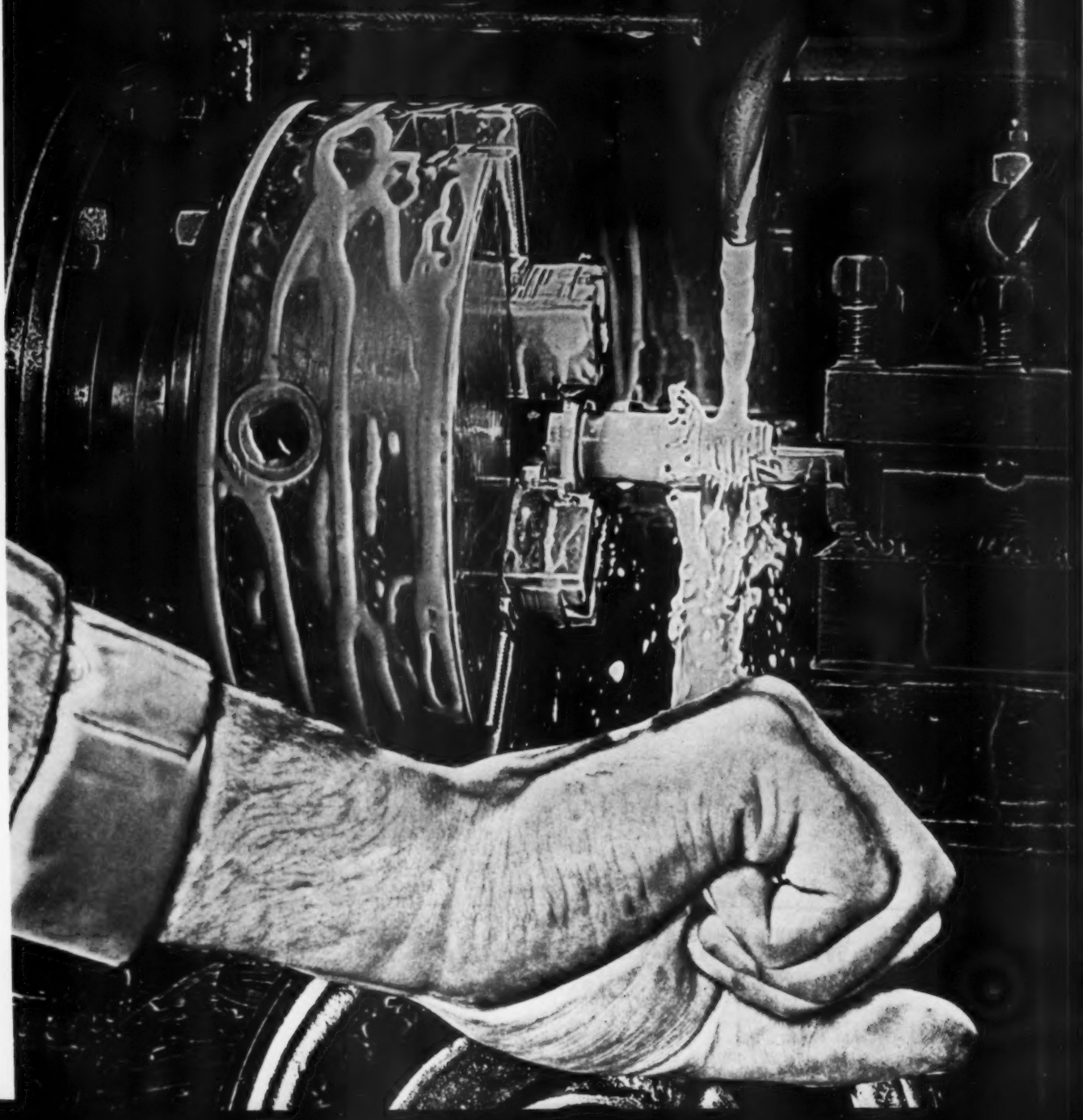


With new Shell Dromus Oils

Most modern soluble cutting oils contain phenolic compounds used as coupling agents between the oil and the emulsifier, for better blending and easier mixing. These phenolic compounds can cause skin irritation, especially where modern high-speed machines are used and the emulsion can concentrate, through the evaporation of water, above the safety level.

Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

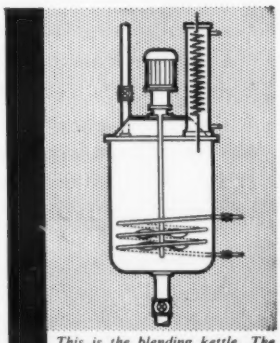
The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organization have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

This field testing and final development proceeded for two years whilst production plants were erected at points so chosen as to give the most economical and rapid delivery throughout the United Kingdom.



This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.

NEW SHELL DROMUS SOLUBLE CUTTING OILS

another proof of Shell leadership in lubrication

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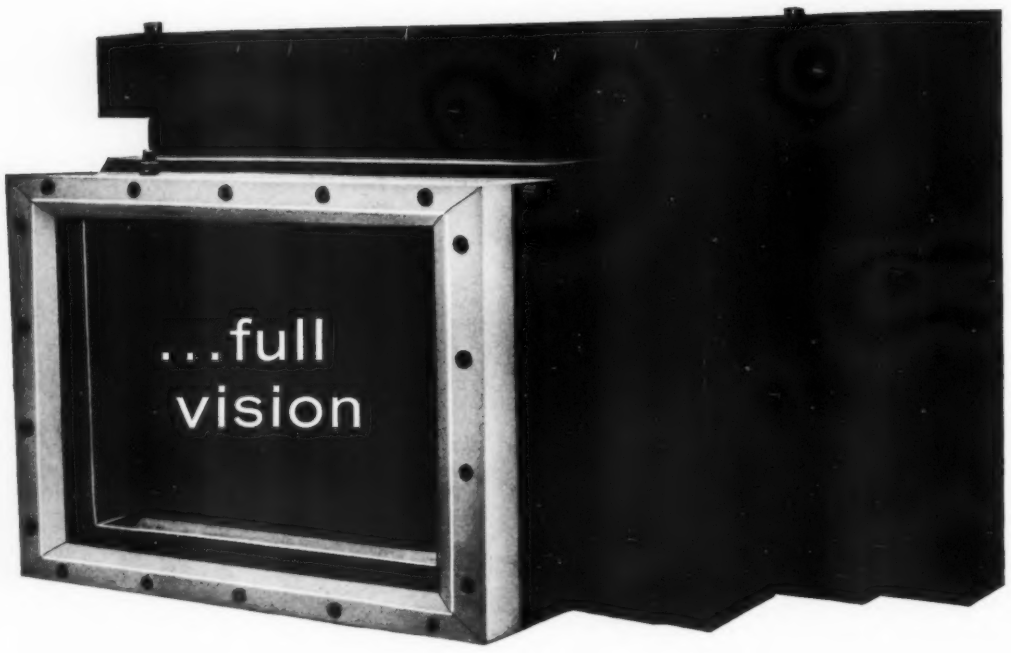
Full protection . . .



The advance of nuclear atomic energy technology has brought with it improvement of design and application of radiation shielding windows constructed by Chance-Pilkington.

Each particular requirement needs the benefit of specialised design experience which will ensure the highest possible efficiency at the lowest cost, and in this respect it is desirable to have the windows custom built to obtain the maximum advantages.

Chance-Pilkington allow for maximum flexibility in design and construction of windows by providing glasses in stabilised and unstabilised form in densities 2.5 gm/cc, 3.3 gm/cc, 4.3 gm/cc and 6.1 gm/cc. These glasses can be supplied in forms from raw unpolished glass to the complete windows ready for installation.

Our free advisory and design service would welcome the opportunity of considering your own requirements.

Shielding Window Advisory & Design Service,

Chance-Pilkington
Optical Works

St. Asaph · Flintshire

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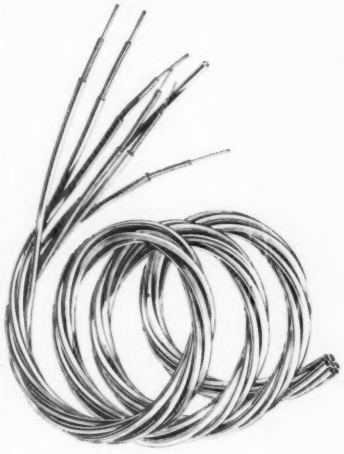
Some recent developments in manufacturing techniques and special applications of tubes in a variety of metals...

NO. 10 OF A SERIES BY ACCLES & POLLOCK

Helically gilled extended surface tubing in zirconium. The gills, which are integral with the base tube and disposed helically around the tube periphery, provide maximum heat transfer properties and strength.



A flexible duct for instrument control which consists of a number of small diameter seamless stainless tubes interwoven to form a single cable and then helically coiled to obtain flexibility. One of the tubes is left open to carry gas and the rest contain insulated wire for the electrical circuits.

Mineral insulated thermo-couple consisting of two dissimilar thermo-electric conductors welded together at a point, embedded in highly compressed magnesium oxide insulant and completely encased in a small, circular austenitic stainless steel tubular sheath.

Designers have a habit of asking for the impossible, but in a surprising number of cases Accles & Pollock produce an answer that enables the production people to translate the concept on the drawing-board into a physical, functional form. Accles & Pollock welcome all such opportunities to co-operate in developing new applications in the form of tubes and tubular sections.

Accles & Pollock

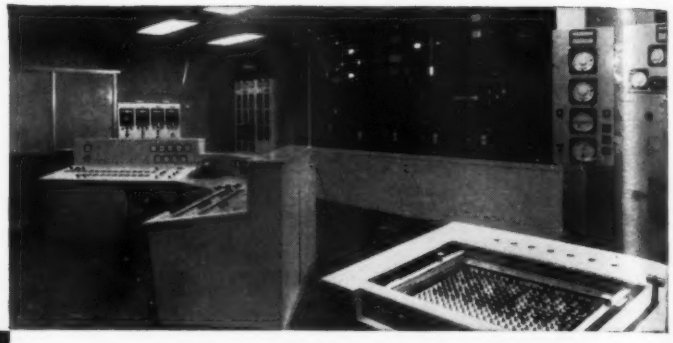
Technical Information Sheets discussing tubes and their applications are available on request.

ACCLES & POLLOCK LIMITED · OLDBURY · BIRMINGHAM · A TI COMPANY

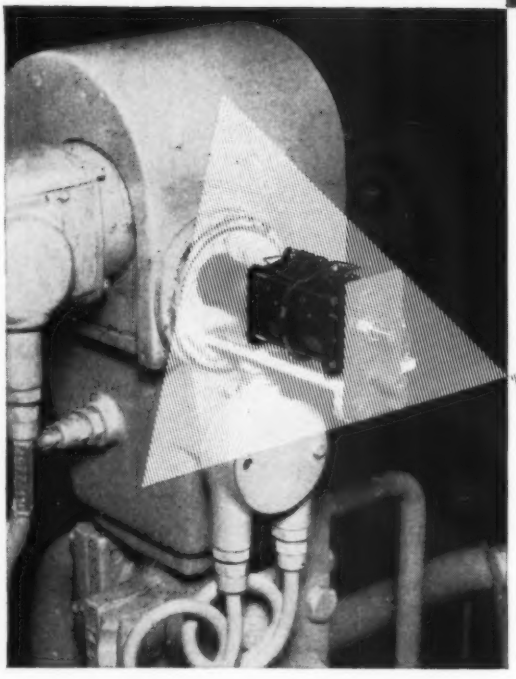
Makers and manipulators of COLD DRAWN SEAMLESS and WELDED PRECISION TUBES in carbon and alloy steels, including stainless steel, and other metals.

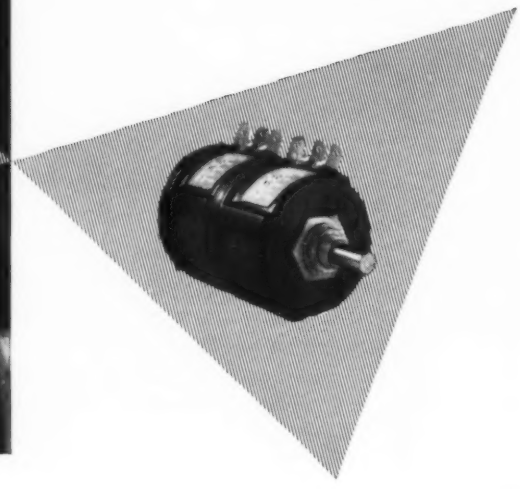
TS W/287

ROLLS-ROYCE *chose* Helipot®



The Rolls-Royce Altitude Test Plant at Derby uses Beckman/Helipot Potentiometers exclusively
for valve position control and generation of control signals.





Above: Series 'C' Helipot, two gang unit, mounted on a large control valve at the Rolls-Royce Altitude Test Plant, Derby. These potentiometers ensure an accurate and fine control of temperature and pressure in the engine test cells, corresponding to the desired altitude conditions.

Helipots provide reliable, long-life operation, embodying 15 years' continuous improvements in design and manufacture.

Beckman/Helipot precision wire-wound helical potentiometers offer: superior resolution . . . superior linearity—continuous test on production . . . low noise—all pots tested to close specification . . . wide ambient temperature range . . . low temperature coefficient . . . long life . . . and can be supplied with multiple taps welded to individual wire turns, without reducing resolution.

We shall be pleased to discuss *your* applications and advise suitable types. All British-made Helipots can be supplied at competitive prices from stock, in a wide range of resistance values.

Special requirements can be met to order.

Write for data sheets to Dept. **NP 3**

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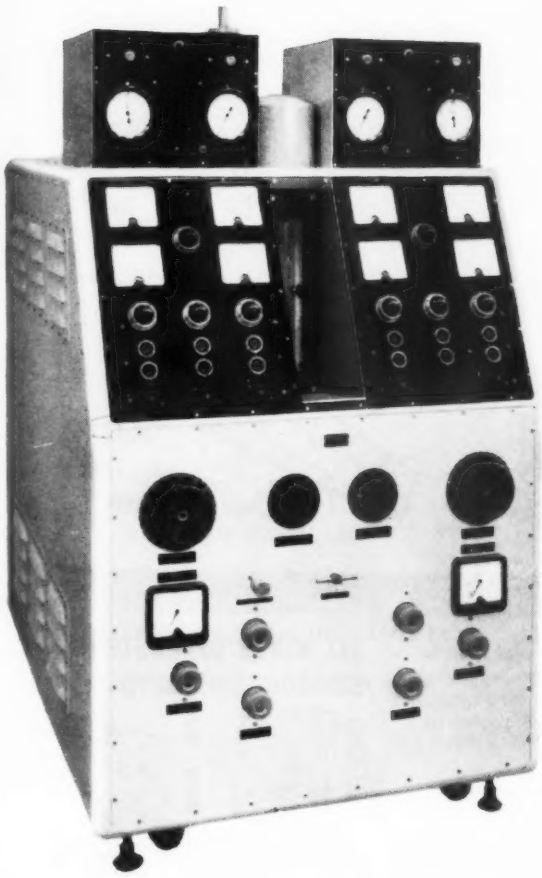

For the removal of moisture, oxygen and nitrogen. For cleaning up the atmosphere in glove boxes. For welding or for any other application where the need arises to remove one or more of the above impurities.

THE MARK IV SELF-CIRCULATING GAS PURIFIER

Supplied in single or in tandem units for long process work. Fully instrumented. Fully automatic

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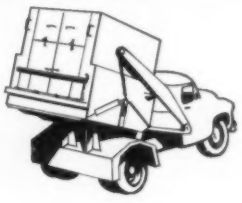
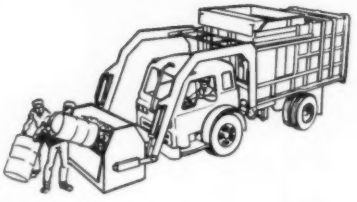
THE
DEMPSTER DUMPSTER
SYSTEMS

the *NEW SYSTEM* of waste disposal

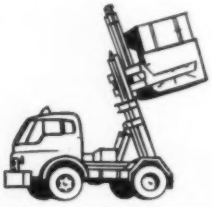


LFW TYPE WITH CONTAINERS IN CARRYING POSITION.

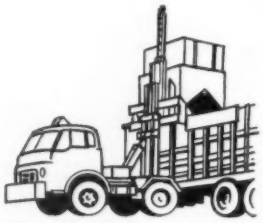


DUMPMASTER CONTAINERS LOADED AT GROUND LEVEL

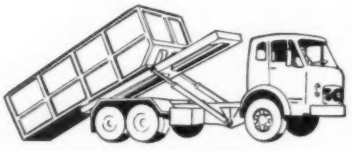
DUMPMASTER CONTENTS EMPTIED INTO COMPACTION BODY



GRD RAISES CONTAINER READY FOR DUMPING



DUMPING FROM A 'DROP BOTTOM' CONTAINER



DINOSAUR FOR BULK DISPOSAL.

The entire waste and by-products of a major industrial plant can be handled by one man—the driver/operator of a Dempster-Dumpster vehicle—and a series of containers strategically located throughout the plant. Unsightly and insanitary rubbish heaps are abolished. Containers are designed to suit every type of application and sizes range up to 15 cu. yards capacity.

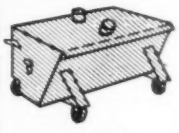
When journeys to outside tips are involved, the "Dumpmaster" range of self-loading, compaction bodied vehicles can lift and empty into their own bodies, containers of up to 6 cu. yards capacity and compress the material in a ratio of up to 3 : 1.

For large scale bulk collection and movement, the Dempster "Dinosaur" is capable of picking up or setting down, off-loading onto raised wharf or tipping to empty, bodies of up to 40 cu. yards capacity.

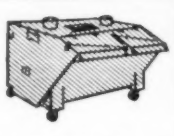
Dempster systems are adaptable to meet every waste disposal problem and are suitable for many process materials handling applications. If you have a waste handling problem or are collecting by conventional methods why not ask for a survey to be made without obligation? Further information on request—films also available by arrangement.

ALL KINDS OF WASTE CAN BE 'CONTAINERISED'

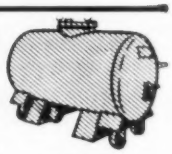
RUBBISH



DUST



SLUDGE



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THERE IS A SYSTEM IN THE DEMPSTER RANGE TO SUIT EVERY REQUIREMENT

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SEE OUR EXHIBIT ON STAND J.16 MECHANICAL HANDLING EXHIBITION — 3-13 MAY 1960

These names make aluminium news. Imperial Chemical Industries and Aluminum Company of America, household words on both sides of the Atlantic, combine to form a new name in aluminium—***IMPALCO.*** Backed by ALCOA's unmatched experience in the specialised field of aluminium and by I.C.I.'s great resources and world-wide organisation, ***IMPALCO*** will provide a new major source of aluminium.

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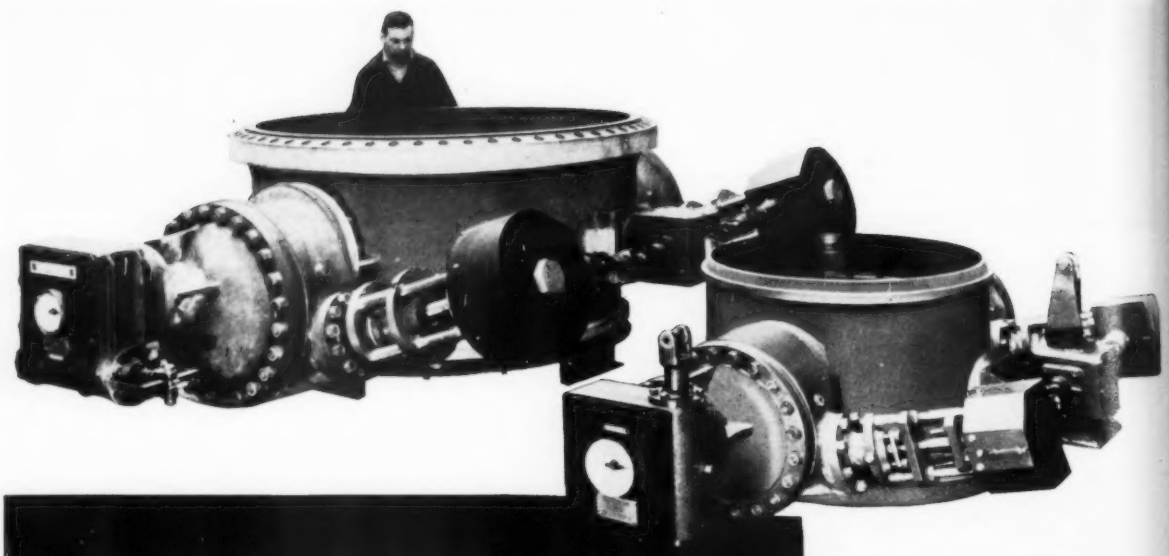
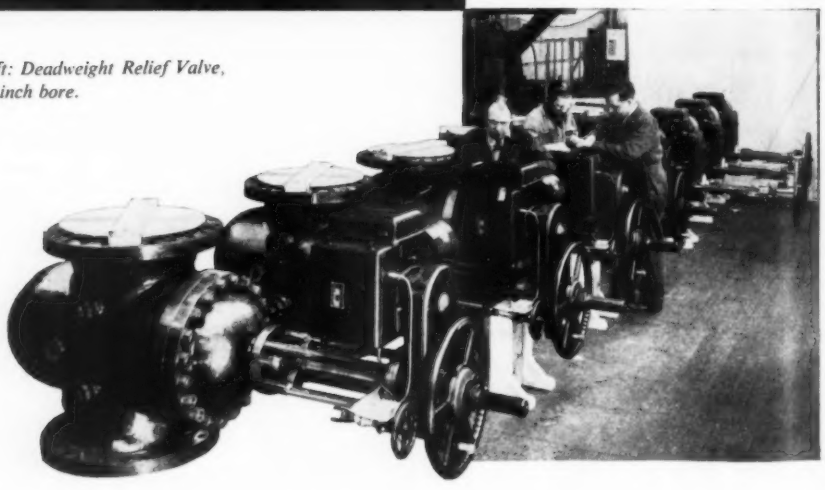


HOPKINSONS' VALVES FOR NUCLEAR POWER STATIONS

Above: "Tansphere" Valves for isolating CO_2 gas between reactor and steam generating plant. Supplied or on order for Bradwell, Hinkley Point, Latina and Trawsfynydd (Valves illustrated are 60 inch and 36 inch bore).

Below: Group of 24 inch electrically - controlled Hopkinson - Ferranti valves for a nuclear power station.

Left: Deadweight Relief Valve, 20 inch bore.



Specialised valves (some of which are illustrated) needed in nuclear power stations are naturally entrusted to Hopkinsons because of their vast experience in the manufacture of valves for exacting duties. But, additionally, Hopkinsons are supplying large numbers of their electrically controlled valves, desuperheating equipment, combined stop and isolating valves, automatic exhaust valves, steam traps and all types and sizes of stop valves.

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Hopkinsons' valves and fittings have been supplied or are on order for:

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Bradwell
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HV121

Rio Tinto is now able to supply

uranium in commercial quantities

for power and research programmes

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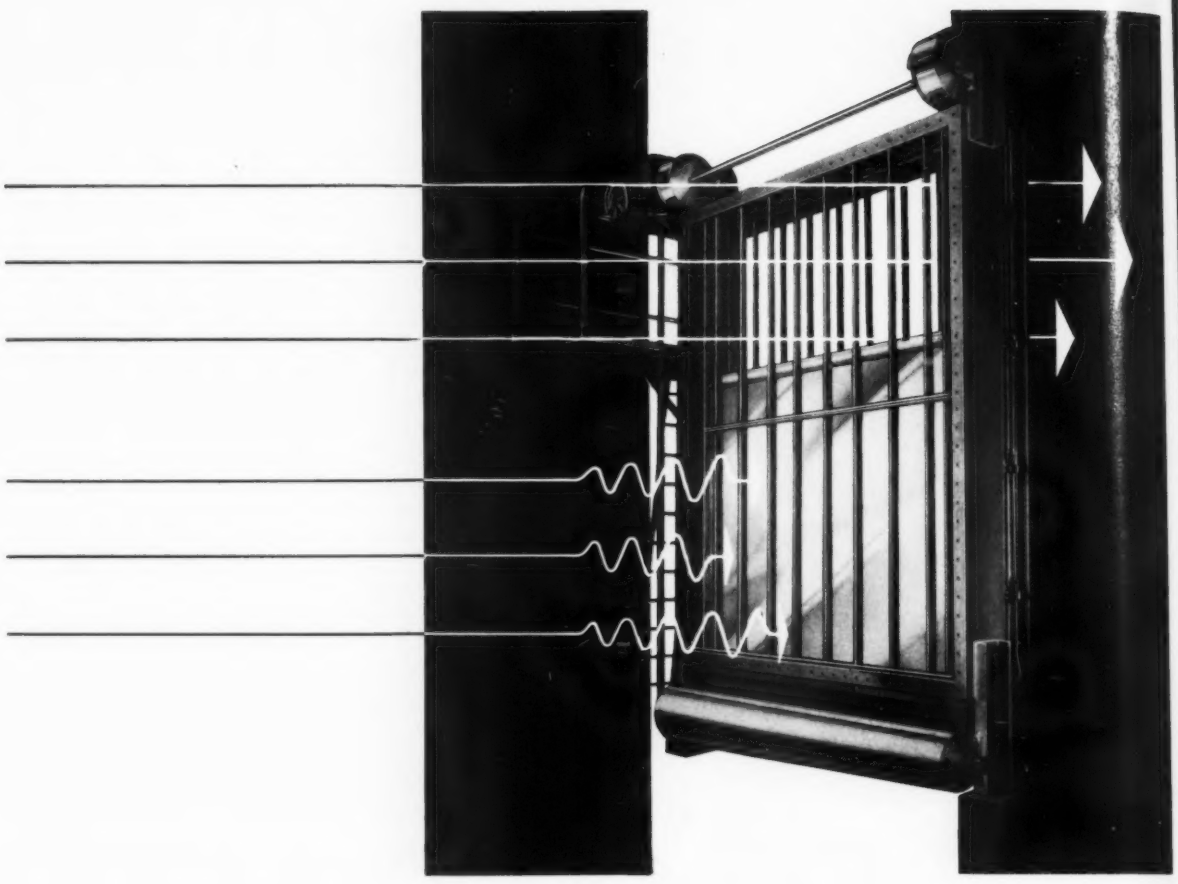
AMMONIUM DIURANATE • URANYL NITRATE HEXAHYDRATE • URANIUM TETRAFLUORIDE • CERAMIC GRADE URANIUM DIOXIDE • URANIUM METAL

Facilities exist for fabrication to individual requirements.

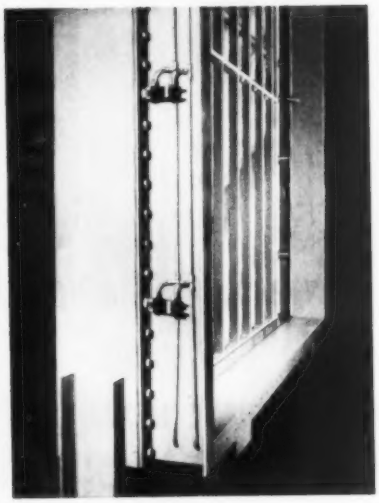
Enquiries are invited to

RIO TINTO MANAGEMENT SERVICES (U.K.) LIMITED

Barrington House, 59 Gresham Street, London, E.C.2. Telephone METROPOLITAN 9101



The Dowling Damper



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Enquiries are invited for application in new Power Station projects, Boiler House installations and other applications in the Gas, Chemical, Cement and other industries where the control of hot gas and dust is required in ducting systems and chimneys. Write for fully descriptive leaflet to:

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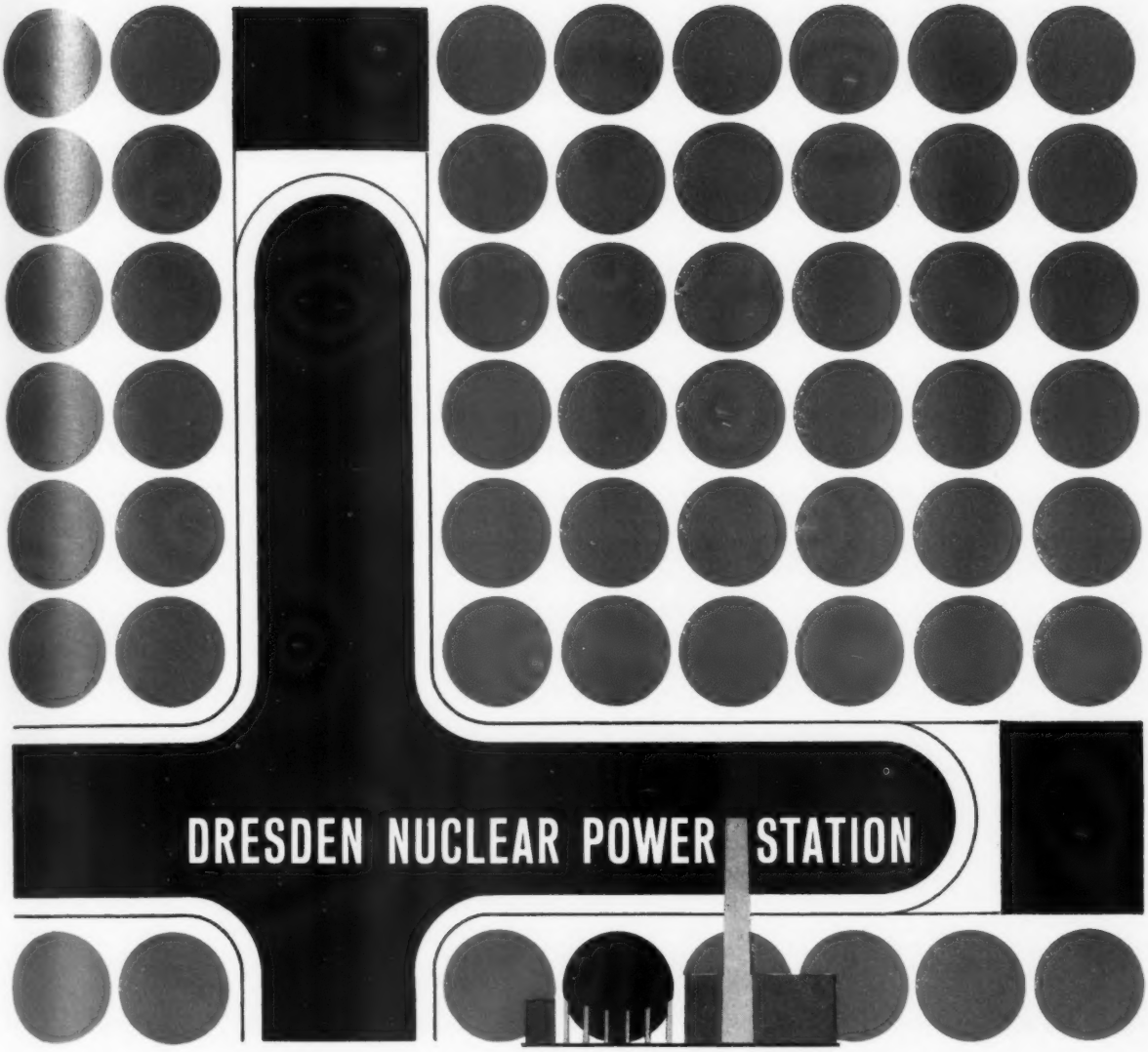

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This reactor, as well as those of Yankee Atomic Power Company and Consolidated Edison Company, depends upon commercially produced nuclear fuels. The uranium loading of all three will be entirely or in part Mallinckrodt UO_2. ◆ As the roster of reactor projects grows . . . so does the number of Mallinckrodt nuclear customers. Whether power, propulsion or experimental—domestic or overseas—Mallinckrodt has unequaled experience in producing nuclear fuel materials. ◆ The core loading of Dresden, designed and fabricated by General Electric Co., will be 136,000 pounds of UO_2 (1.5% enrichment) . . . equal to approximately 1,800,000 tons of coal. This 180,000-kilowatt plant will be owned by Commonwealth Edison Company. ◆ Mallinckrodt produces more than fifteen different forms of uranium compounds and metal. Now, with the completion of an automated pellet plant, Mallinckrodt can deliver completed fuel elements by working with metal fabricators. ◆ For consultation on nuclear fuel problems write or call Mallinckrodt.

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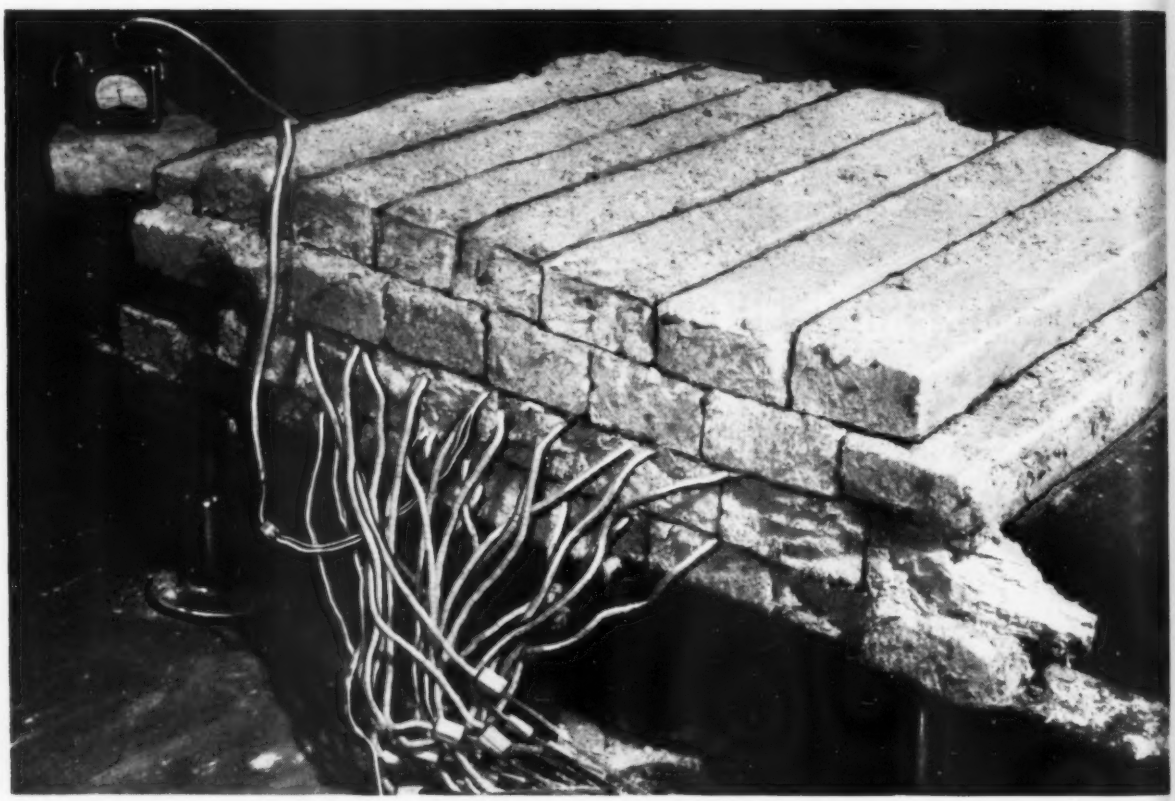
● FOR STRESS RELIEVING OF WELDS ● WORK OFF GENERATORS OR TRANSFORMERS



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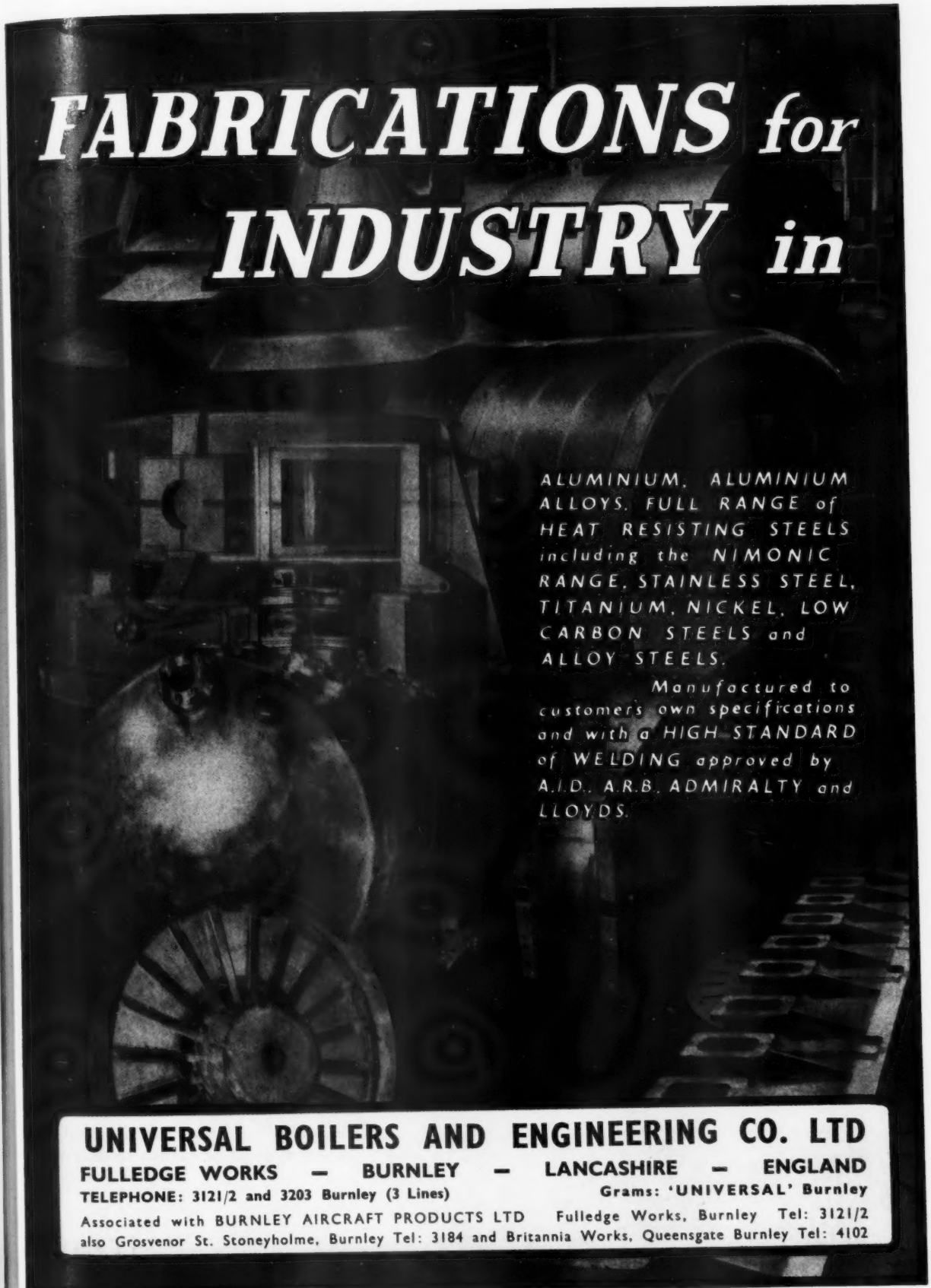

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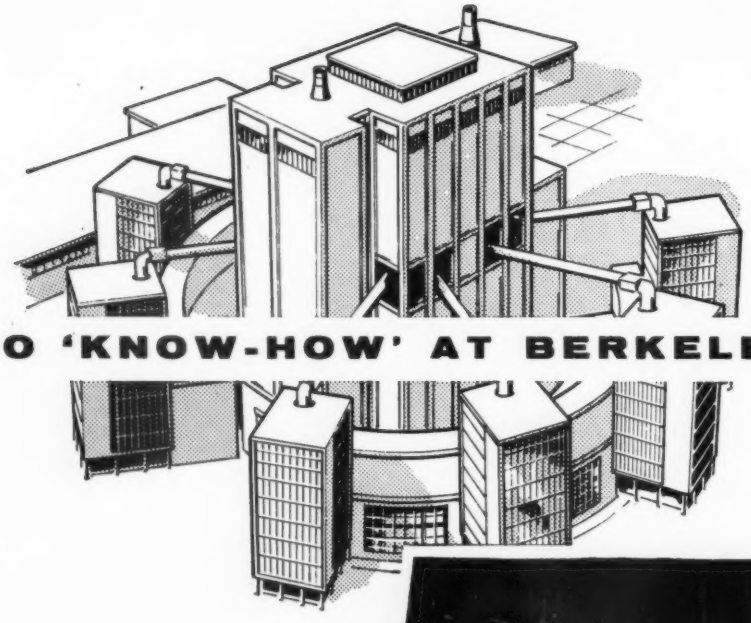

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Reactor pressure vessel stress relieving installation planned, erected and supervised by EFCO

Efco heating equipment inside the world's largest reactor pressure vessel ever to be stress relieved.

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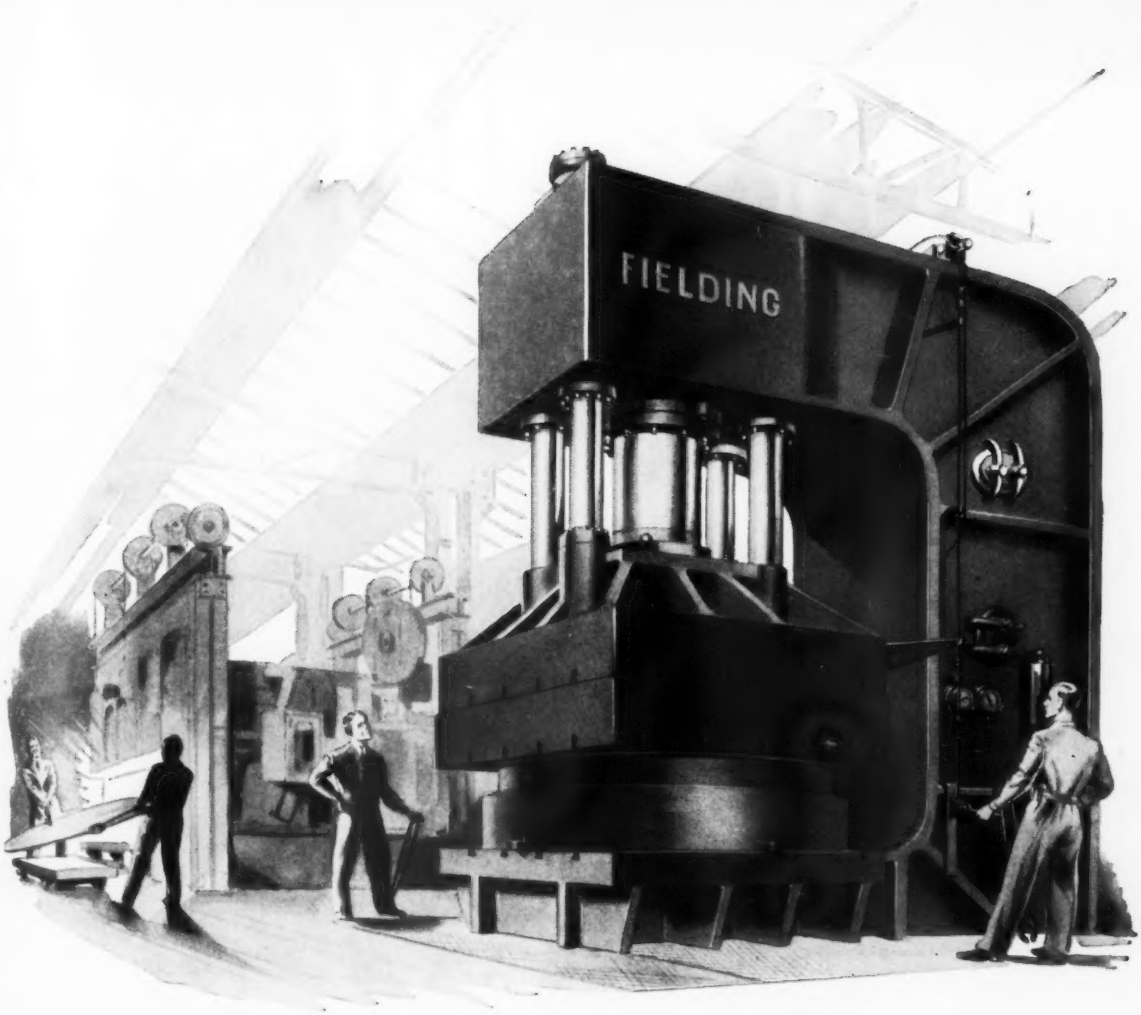

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A wide range of "Fielding" Hydraulic Open Gap Presses is available, covering a variety of applications. These Presses are supplied complete with self-contained pumping equipment, or alternatively to operate from an Accumulator System....Your enquiries will receive our careful and prompt attention.

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Britain's Atomic Power Stations

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PLANNAIR GAS CIRCULATION BLOWERS FOR NUCLEAR PROJECTS

Re-affirming their leadership in matters of forced fluid flow temperature control, Plannair are now engaged upon intensive design and development of gas circulating blowers for various nuclear projects.

Ambient pressures in which these circulators work range from normal atmospheric to 300 p.s.i. at temperatures up to 350°C . . . and the gases involved are carbon dioxide, nitrogen and helium. Pressure rises through circulators extend up to 30 p.s.i. and flows through units cover a range up to 8000 lb/hour.

Circulators are usually of the high speed motor driven type with specially designed radial impellers, motors being gas and liquid cooled.

Zero leakage is an important feature of these designs.

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Atomics International is also building large power reactors for electric utilities in Ohio and Nebraska under AEC programs. Studies are underway for other power reactors in the United States and Europe. Research reactors have been built by AI for Denmark, Germany, Italy, Japan, Puerto Rico and several sites in the United States.

For details contact: ATOMICS INTERNATIONAL, Canoga Park, California, U.S.A. Cable address: ATOMICS.

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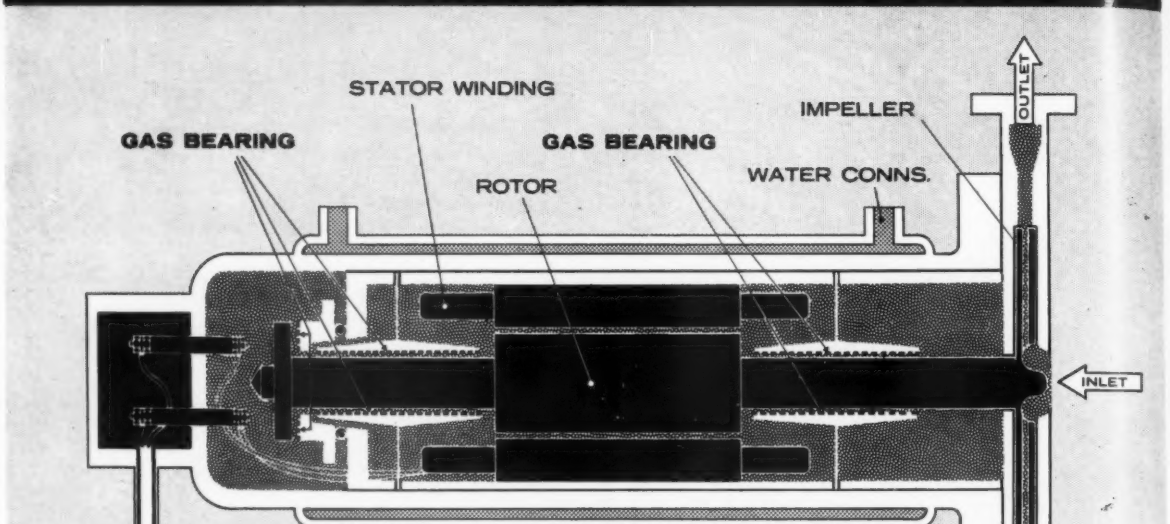

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One of the largest manufacturers of motive power units in the world, Bristol Siddeley Engines Limited produce gas bearing compressors. The range covers a very wide performance capacity, from 0°—700°C gas operating temperature, 15—2,000 psi and 0.5—2,000 hp power input.

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Bristol Siddeley gas bearings were developed originally to meet the extremely fine limits of operating purity and precision of manufacture demanded by the advent of nuclear engineering. But gas bearings have many other applications where a rotating shaft must be supported in such a way that no contamination and leakage can be allowed and where the supply of chemically pure fluids or gases is essential: in the textile, chemical engineering, pharmaceutical, food storage and processing industries, to name but a few.

For further information about Bristol Siddeley gas bearing compressors and gas bearings, please write to H. J. Prince, Sales Manager, Reactor Components Division, Bristol Siddeley Engines Limited, P.O. Box 17, Coventry, England.

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Vokes 'Absolute' filters have been developed for applications where radioactive and other toxic dusts may be encountered, and an extremely high degree of efficiency is therefore required. The filters have a guaranteed efficiency of at least 99.95% against particles in the 0.1 to 0.5 micron range, each panel being individually tested against a methylene blue dust cloud. Unlike many filters of this efficiency, the Vokes 'Absolute' is compact and light weight and the use of a special paper medium combined with an absence of metal parts facilitates the disposal of a contaminated panel.
Special variations of the 'Absolute'—High Humidity, High Temperature, Flameproof and High Acid Resistance types—use a glass paper medium with *an efficiency as high as* 99.99%.

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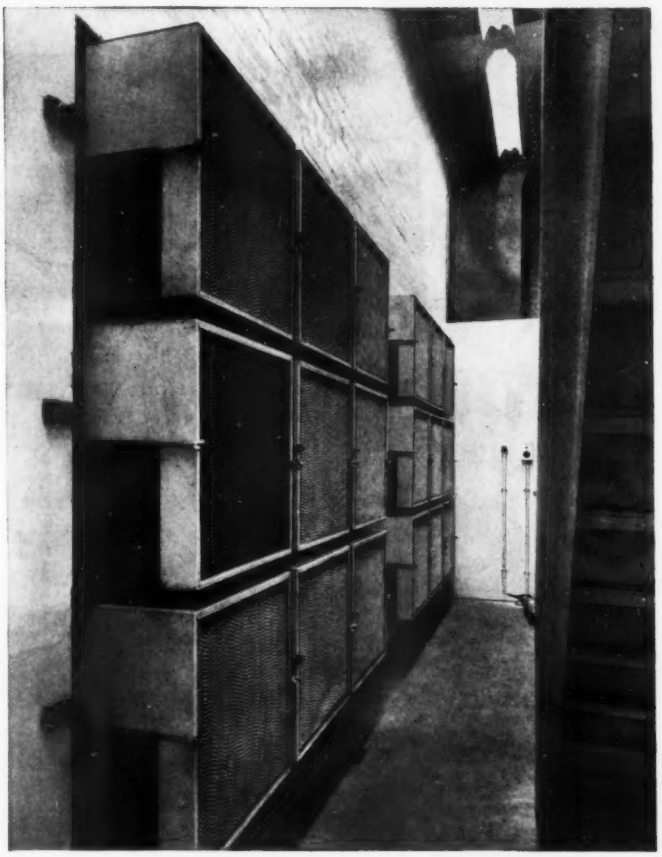
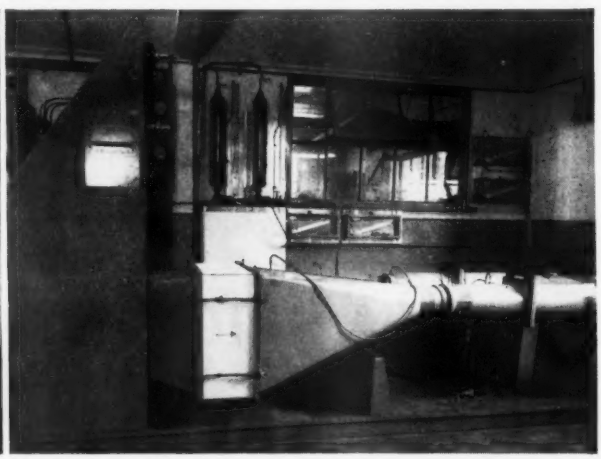


A bank of Vokes 55 'Absolute' filters specified by the Ministry of Works for the ventilation plant (Extract) in the High Activity Materials Handling Building, Harwell. Vokes 44 'Absolute' panels are used on the intake.

A pressure-suited operator changing a filter in the ventilation system of the G.E.C. beryllium laboratory at Erith, where beryllium dust if not trapped could endanger human lives. Other Vokes filters are fitted to equipment used in the laboratory.



The methylene blue test rig—part of the equipment in the large Vokes filter laboratories at Henley Park. Guaranteed performance figures are stencilled on each filter case.

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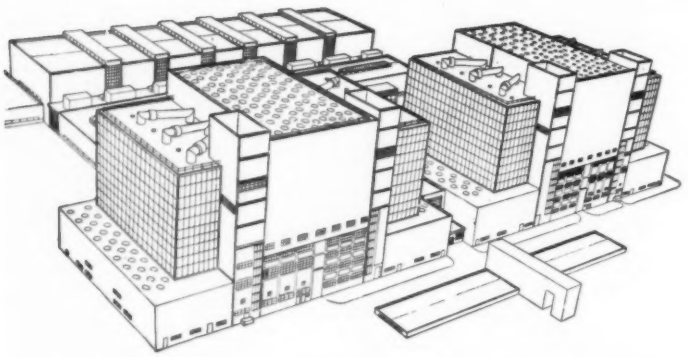

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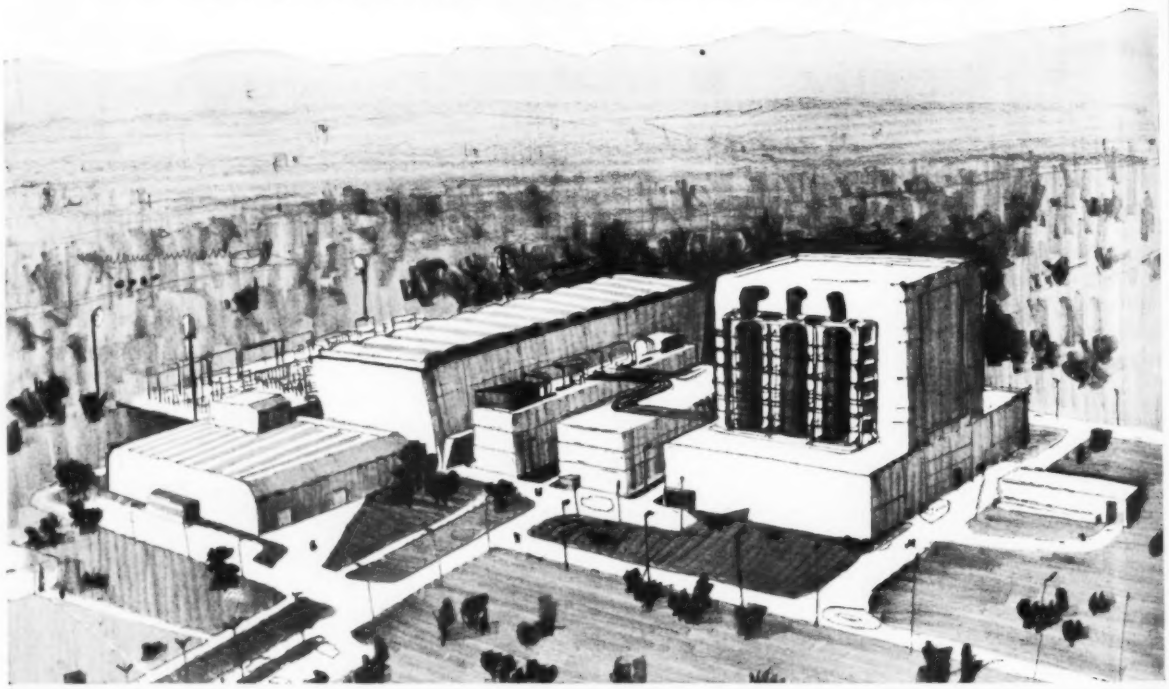

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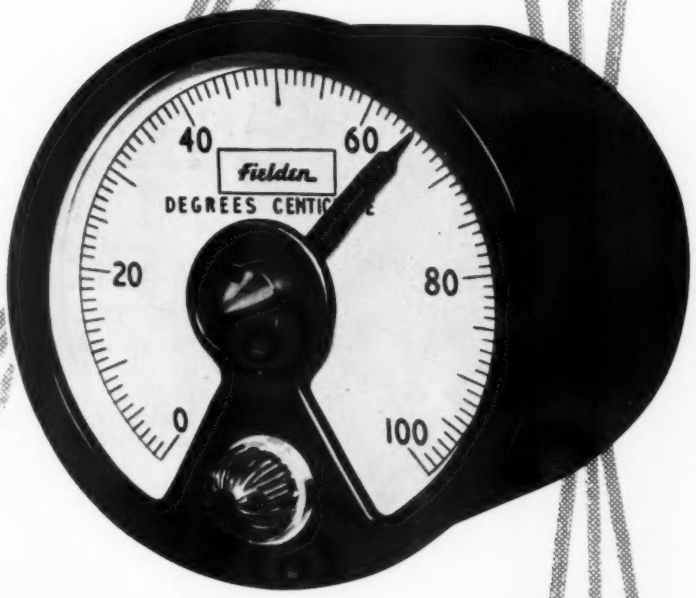

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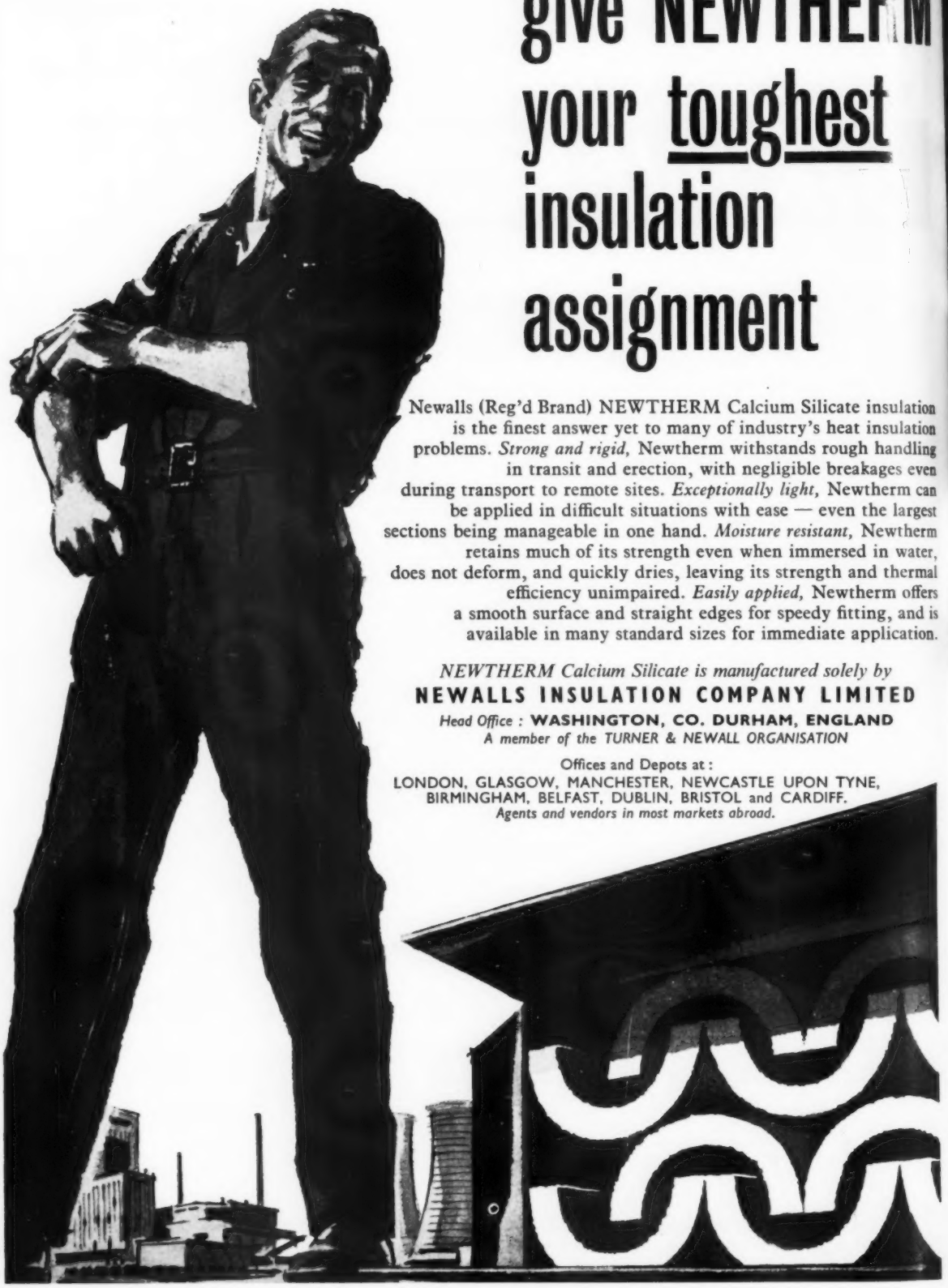

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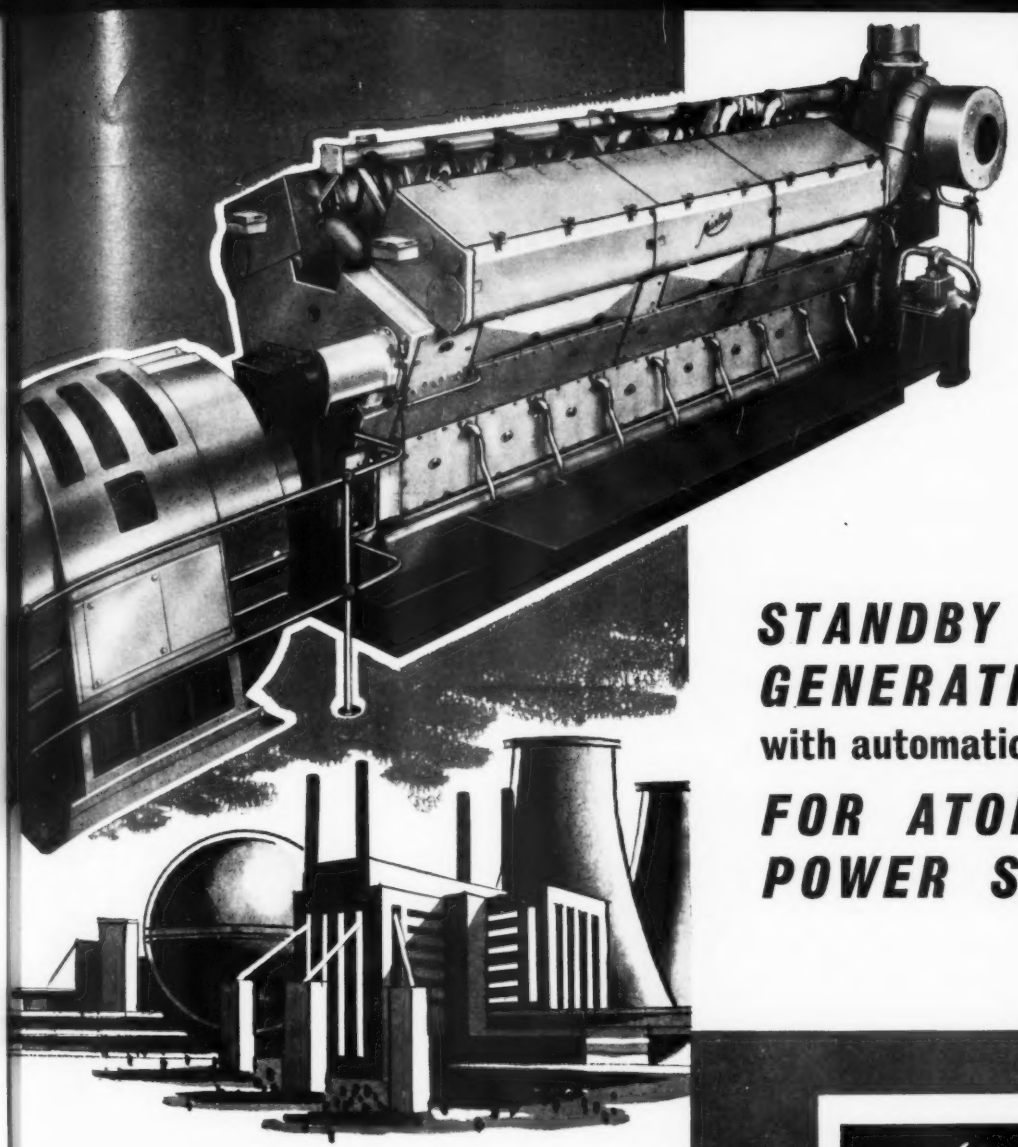

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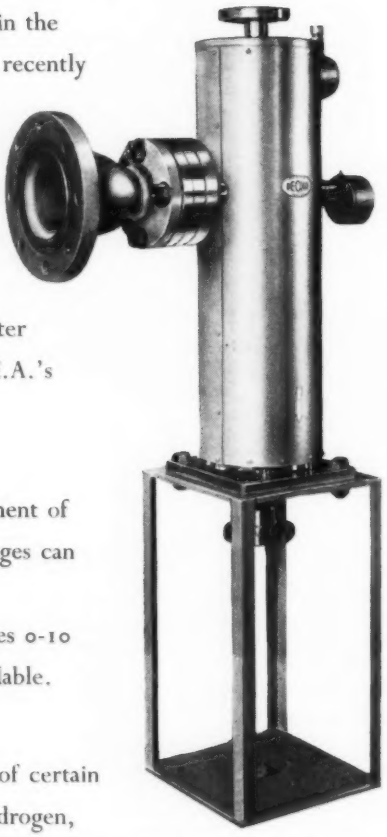
Engelhard Industries who have, for many years, specialised in the problems associated with gas purification and analysis, have recently supplied to McKee Head Wrightson Limited the following equipment for use on the Danish D.R.3 Reactor.



DEOXO RECOMBINATION UNIT

This unit makes use of a supported platinum group metal catalyst to promote the recombination of oxygen and deuterium emanating from the dissociation of the heavy water moderator. A unit of this type is also used on the U.K.A.E.A.'s research reactors ' DIDO ' and ' PLUTO '.

DEOXO INDICATOR

The Deoxo Indicator provides for the continuous measurement of oxygen, hydrogen or deuterium in other gases. Various ranges can be used up to 2% for hydrogen and 1% for oxygen.
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This provides for the catalytic hydrogenation or oxidation of certain gases such as oxygen, hydrogen, carbon monoxide, etc. Various types of laboratory and commercial purifiers, embodying the Deoxo process and using different platinum metal catalysts, are available. The principal advantage of the ' Deoxo ' process is that, with negligible operating costs, a very high degree of purification can be achieved—in many cases the remaining impurity being less than 1 v.p.m. (0.0001%).

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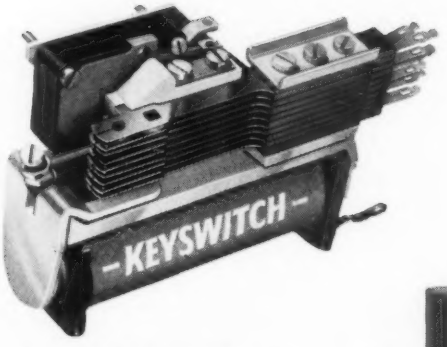
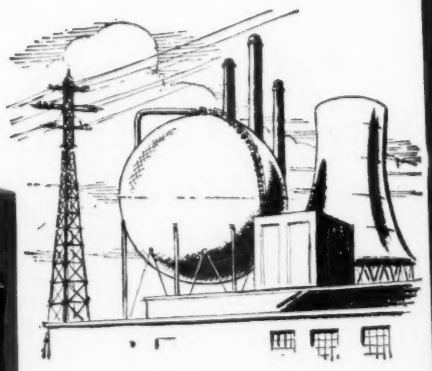


Special combined circuits fitted with 5 amps microswitch and 9 standard 0.3 amp contacts.



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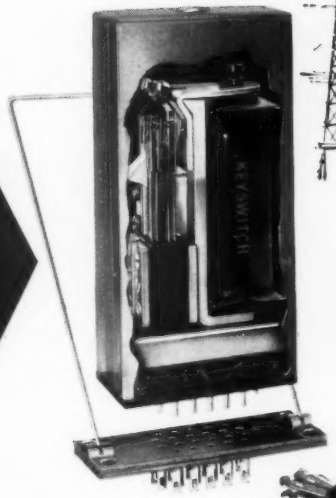
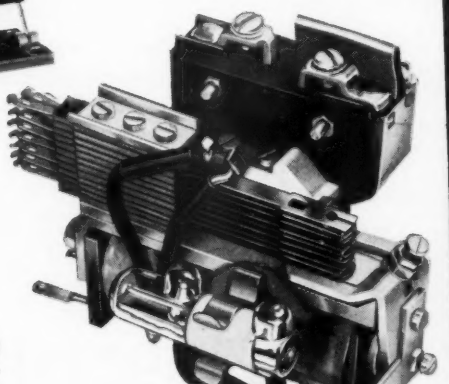


This relay incorporates 15 amp. Micro Switch, 5 amp. Mercury Switch and Standard 0.3 to 8 amp. contacts.



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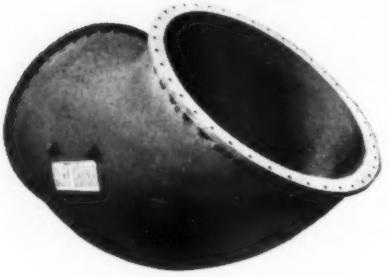

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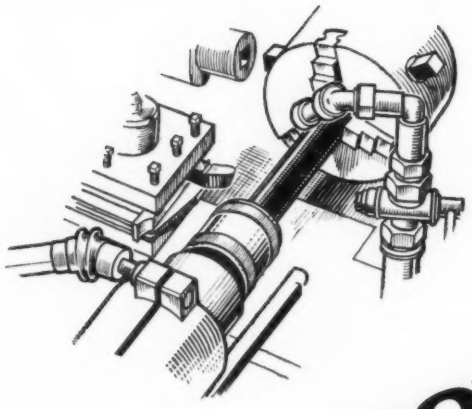

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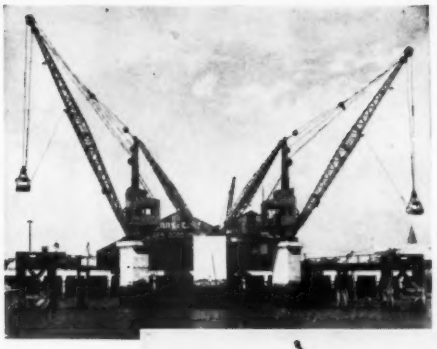

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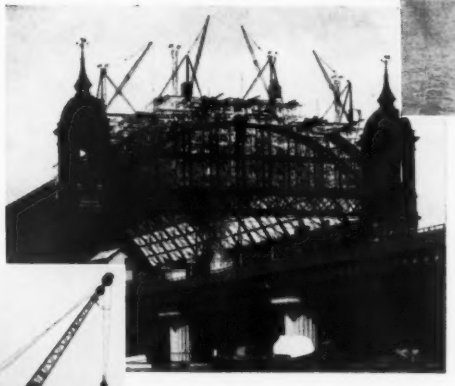

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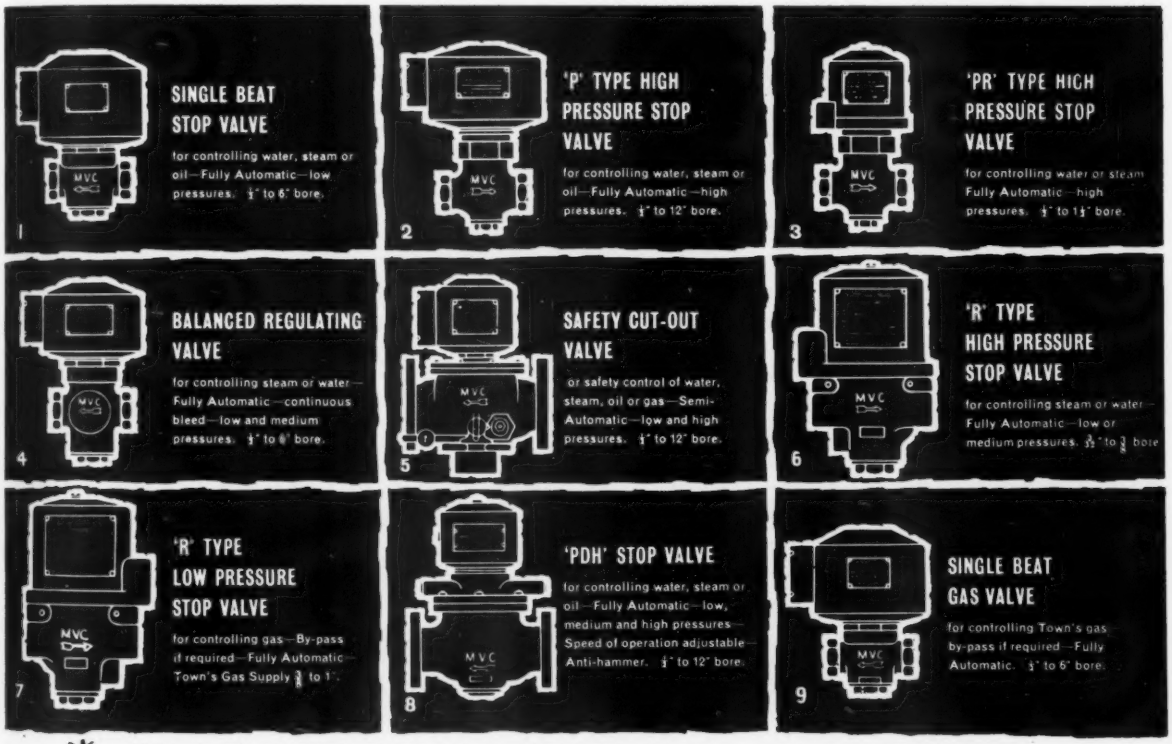
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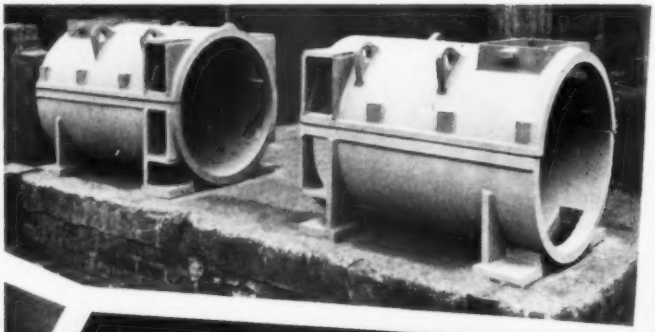

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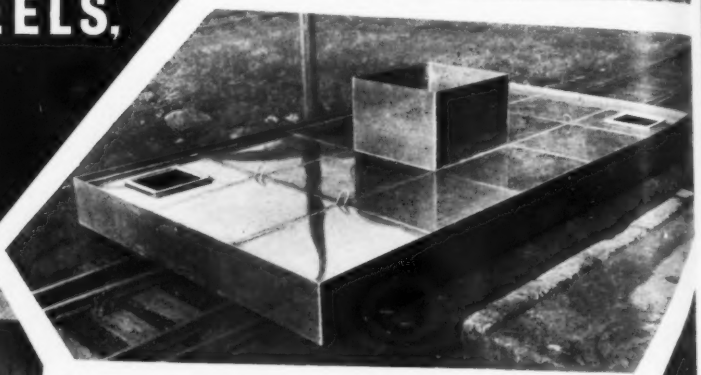

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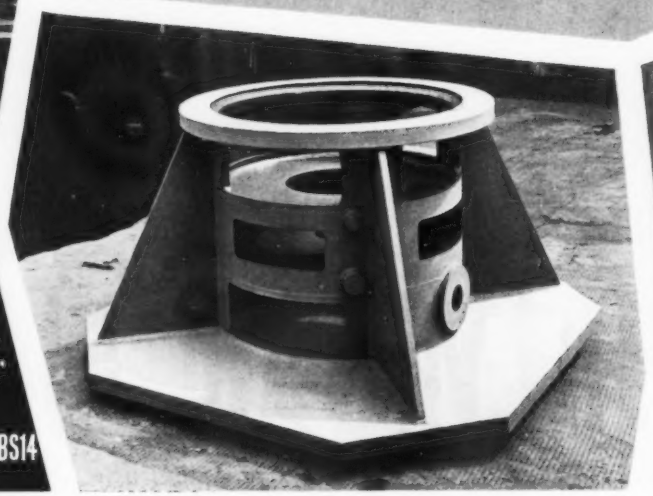

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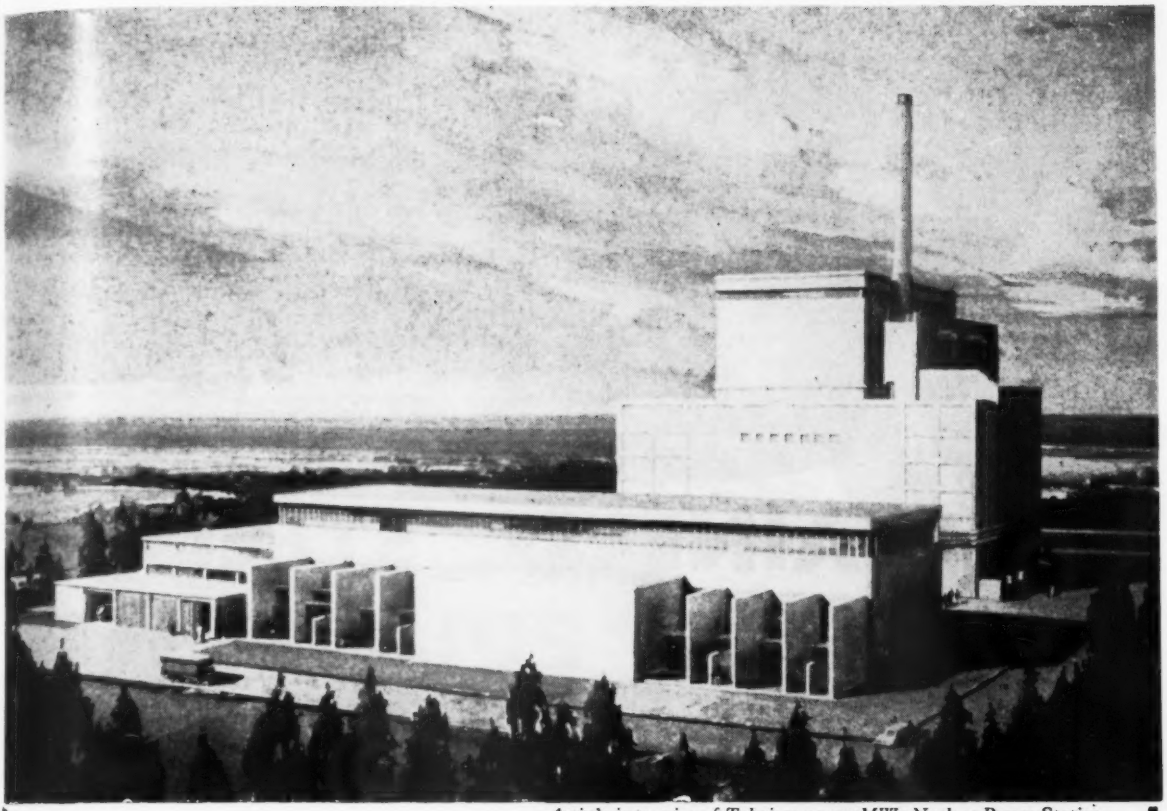

Artist's impression of Tokai-mura 150MWe Nuclear Power Station

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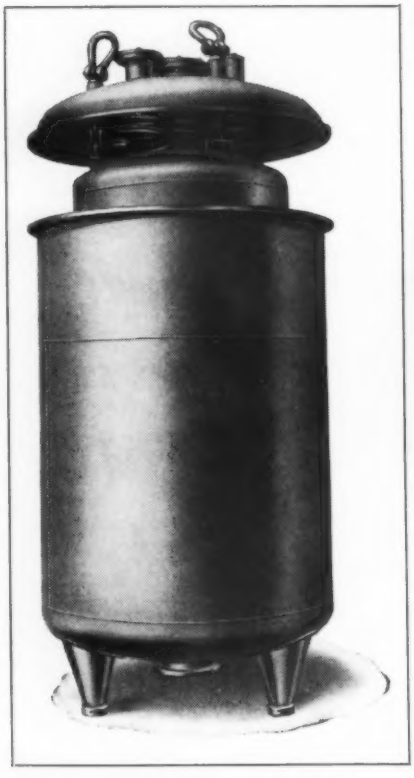

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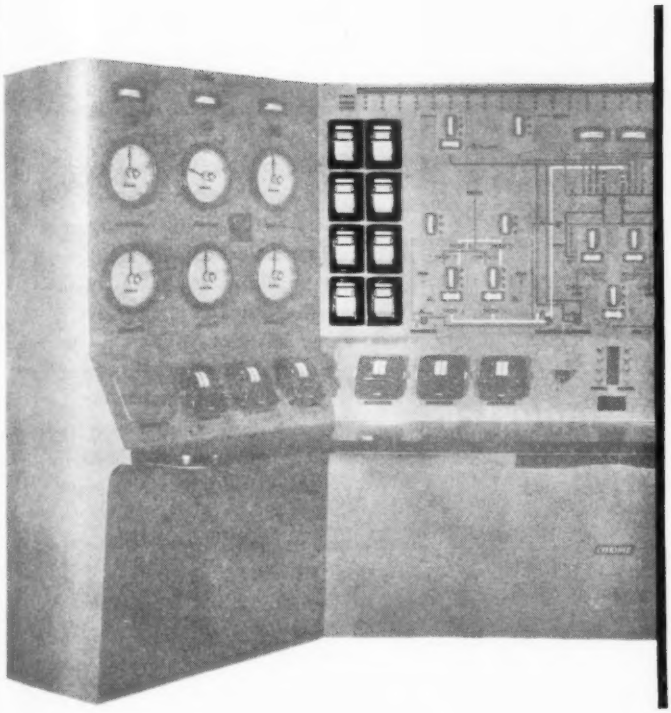

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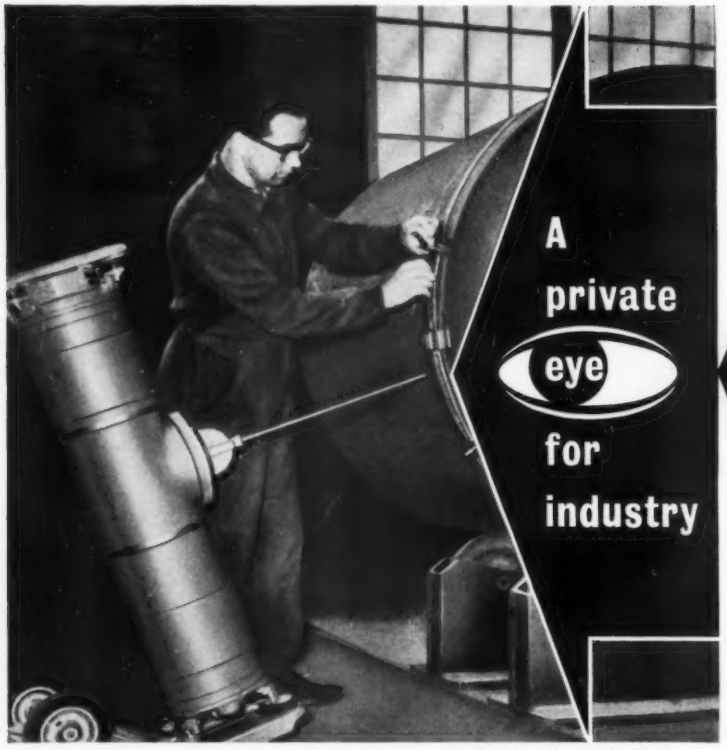

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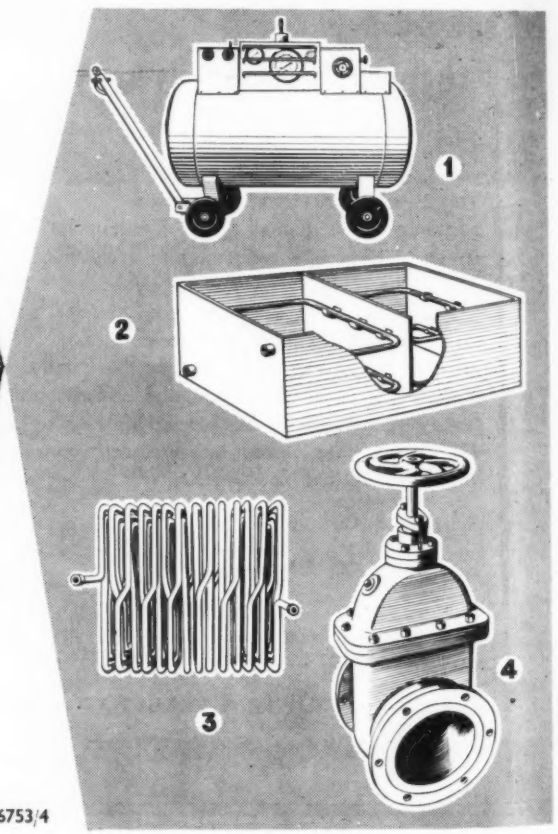

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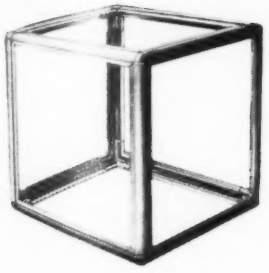

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4 Schraube in jeden Verbindungsarm einsetzen und festschrauben, sodass das Gestell starr verbunden ist.

1 **Couper la longueur de métal extrudé désirée**
2 **Biseauter les extrémités des brides; des gabarits IMLOK spéciaux facilitent la tâche**
3 **Faire glisser la pièce extrudée sur des connecteurs préparés d'avance**
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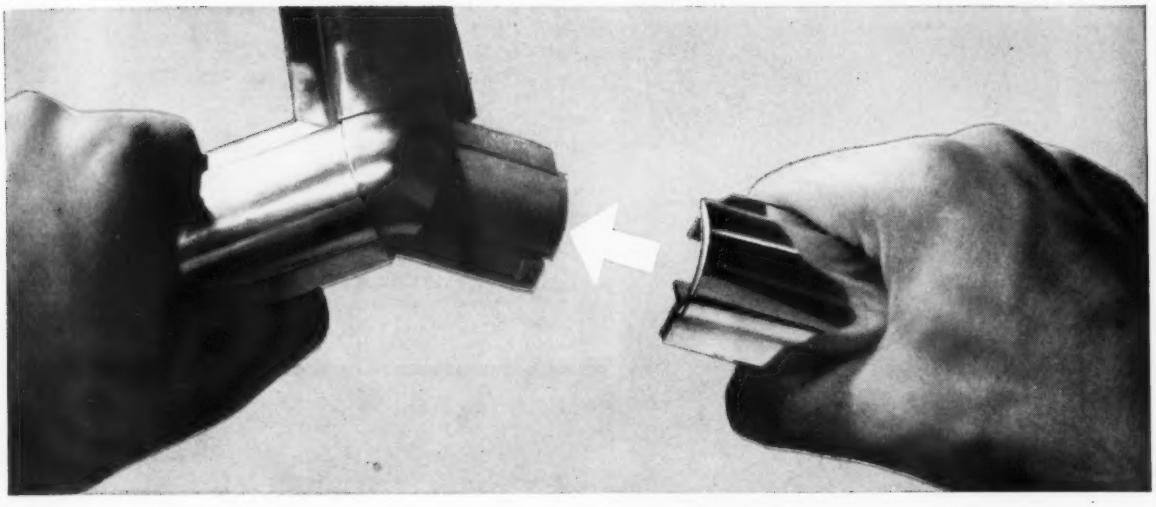

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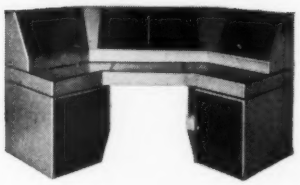

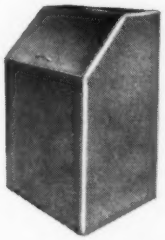

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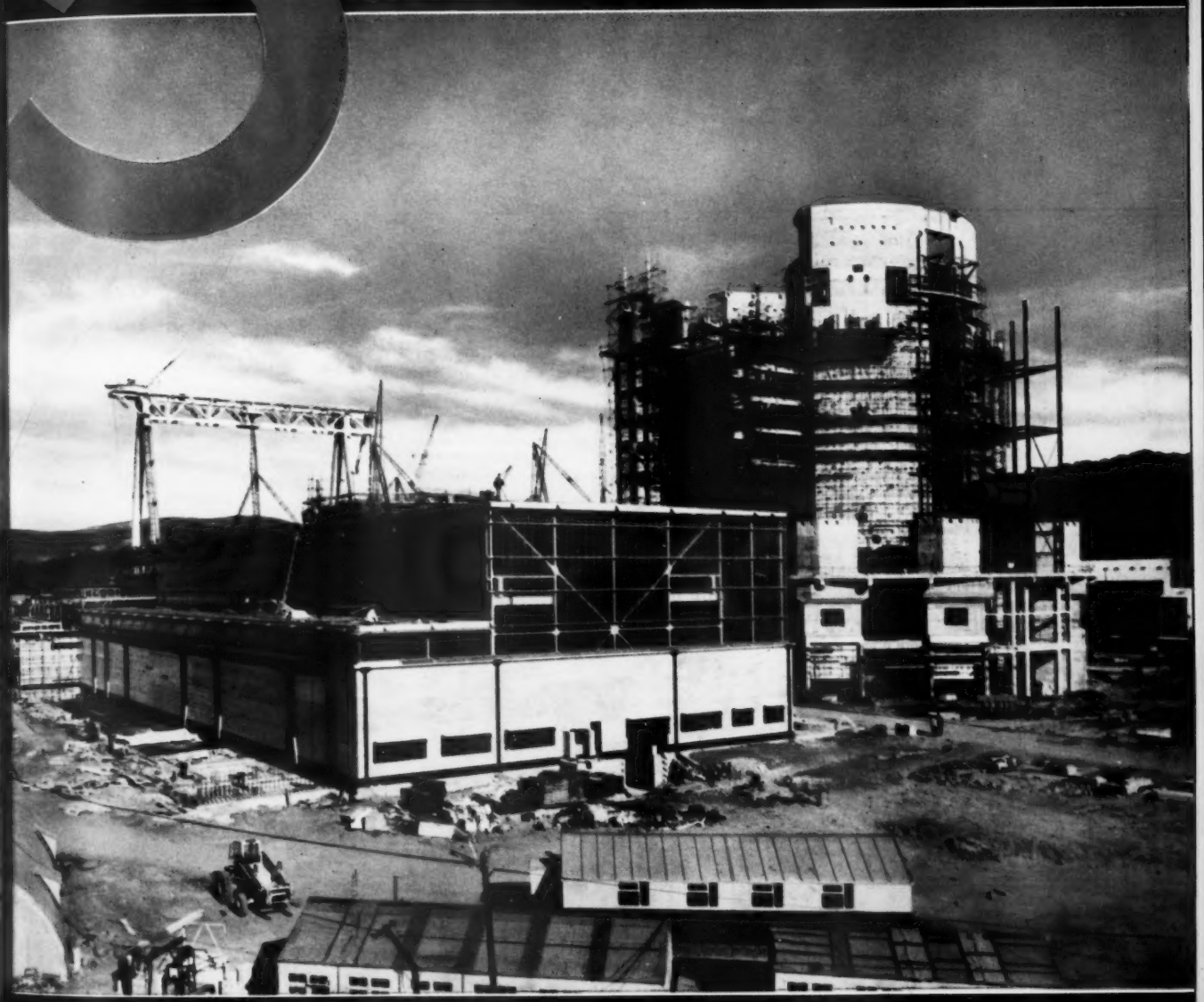

1

At Hunterston, on Scotland's west coast, the construction of one of the world's first full-scale nuclear power stations is reaching an advanced stage. This 320 MW station, which is being built for the South of Scotland Electricity Board by The General Electric Co. Ltd. of England in association with Simon-Carves Ltd. will be powered by two gas-cooled graphite-moderated reactors.

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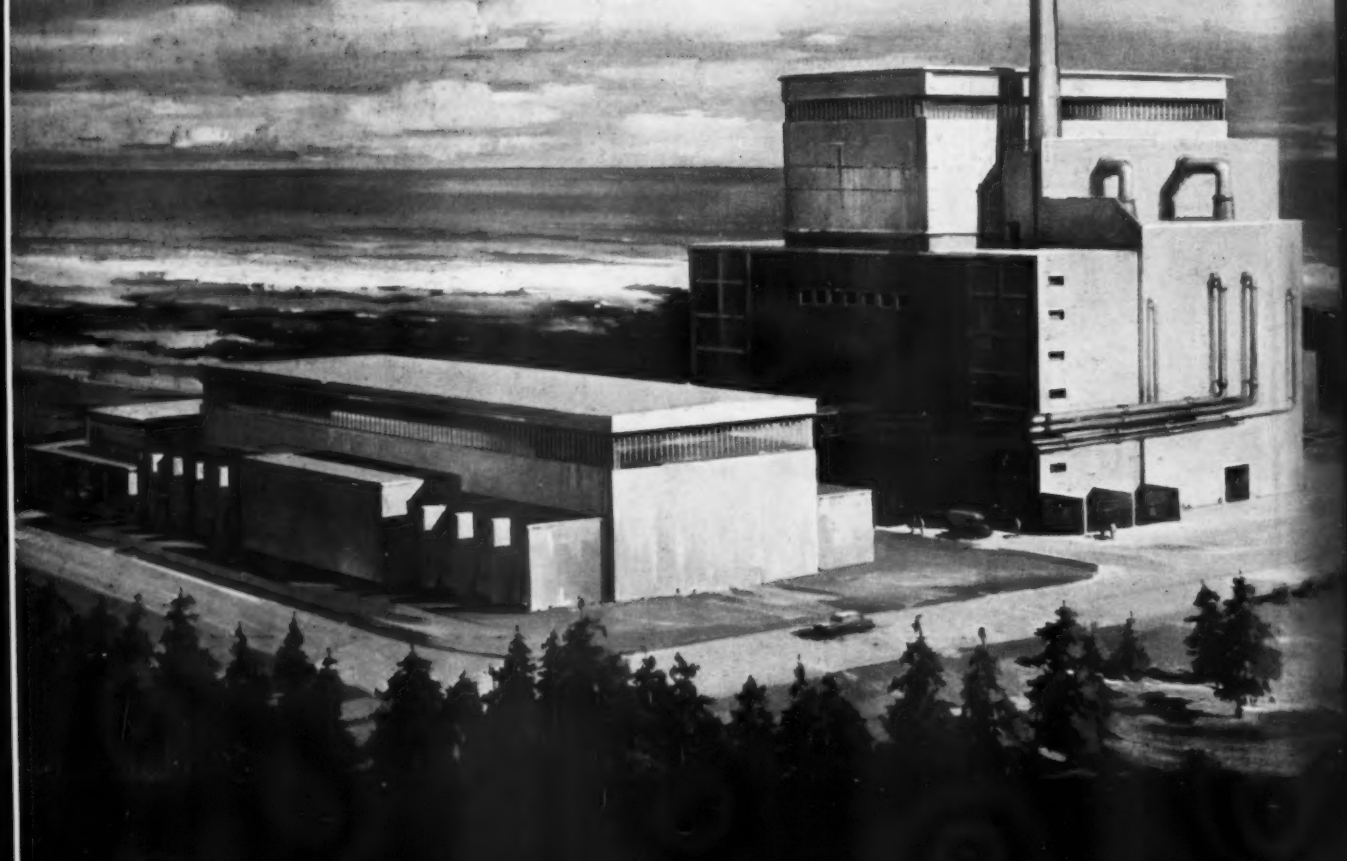
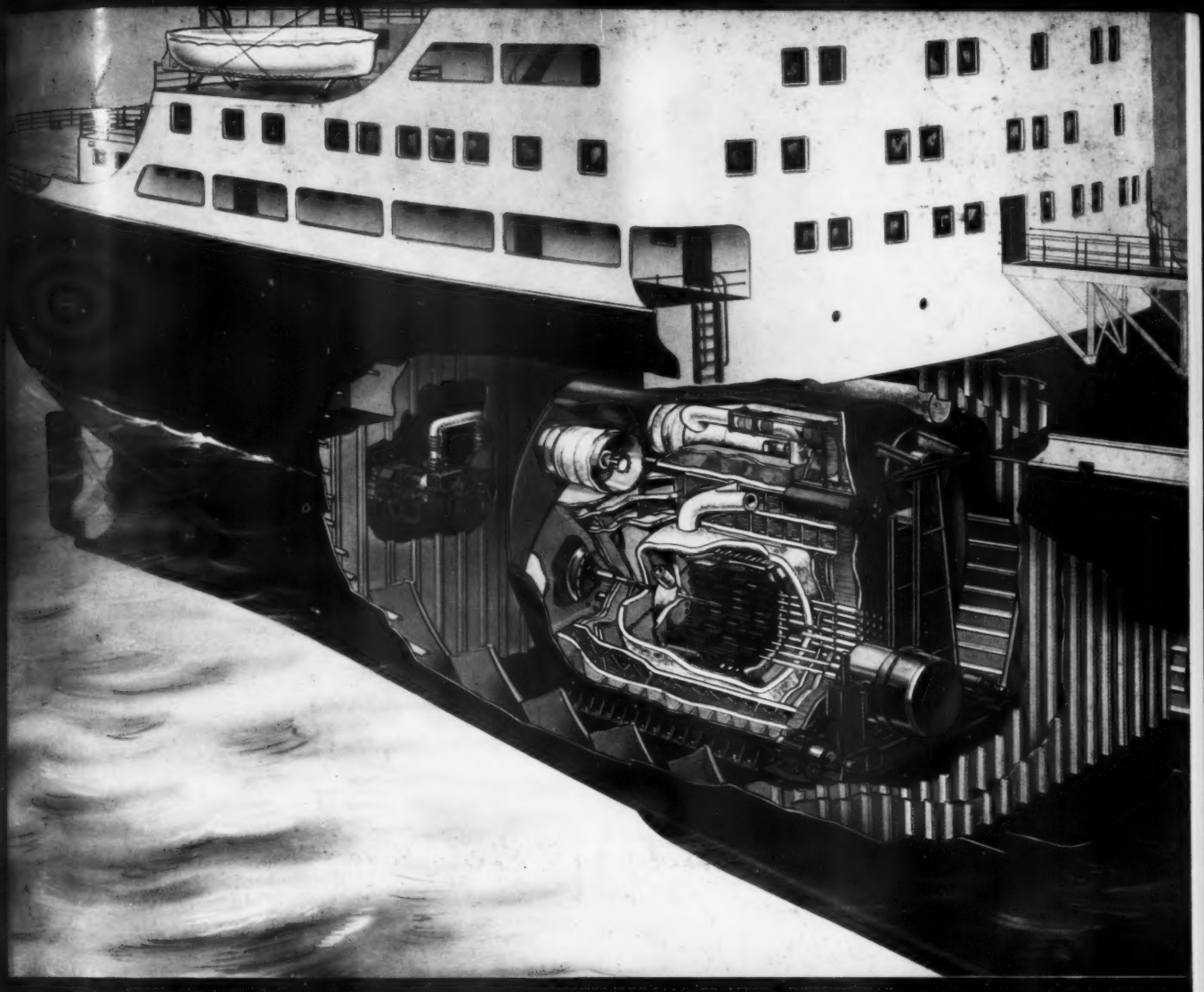
The General Electric Company Limited of England and Simon-Carves Ltd. were among the first industrial organizations in the world to enter the field of nuclear engineering.

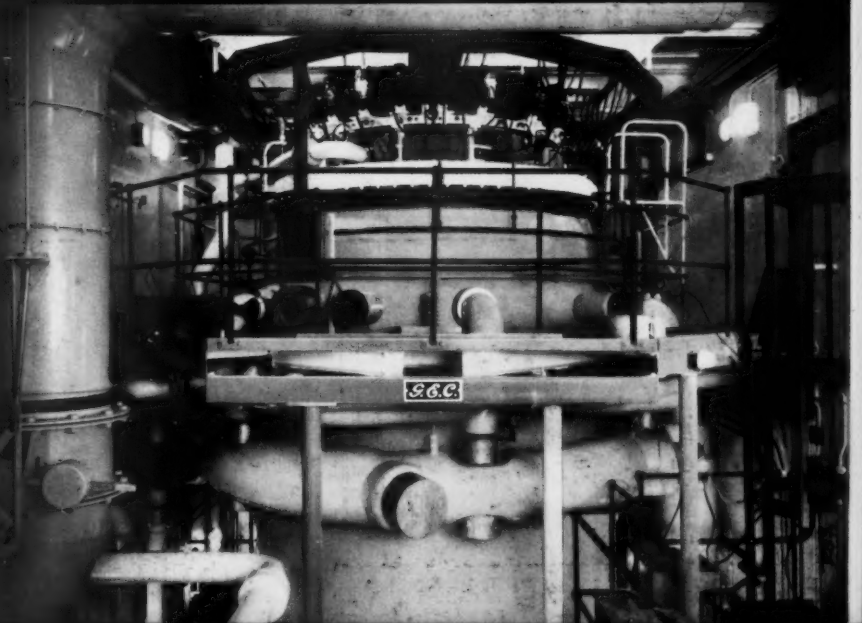
Already the two companies have developed the five types of reactor illustrated. Two of them are for full-scale power stations which are being built on opposite sides of the world; but progress now extends beyond land-based nuclear power stations to embrace reactors for ship propulsion, research and training. Vital new contributions are still in the planning stage.



2 G.E.C. and Simon-Carves have been awarded the contract to build Japan's first nuclear power station at Tokai-Mura, 70 miles from Tokyo. The 150 MW gas-cooled reactor design is of particular interest and importance because of the special features which have been introduced to ensure the safety of the installation under severe earthquake conditions.



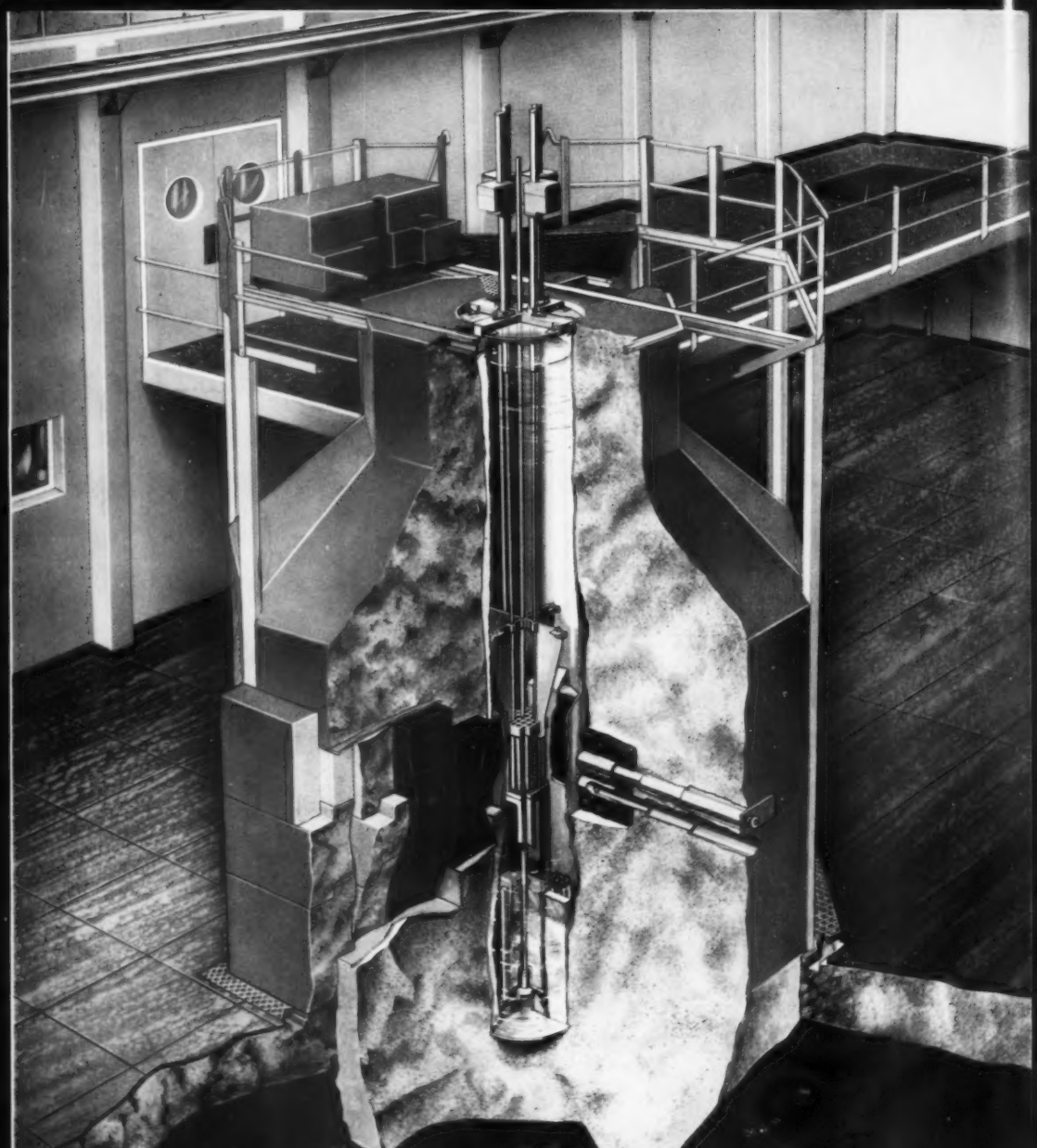
3 G.E.C. and Simon-Carves have developed a revolutionary design of advanced gas-cooled reactor incorporating for the first time a cross-flow fuel element. So compact and so efficient is this new reactor that nuclear-propelled ships and small nuclear power stations down to 20 MW capacity become immediate economic possibilities.



4 Zenith, a zero-energy reactor built by G.E.C. for the United Kingdom Atomic Energy Authority and designed in collaboration with them, operates at 800 C, a higher temperature than in any other reactor in the world. It represents a most important stage in the evolution of the promising high-temperature gas-cooled reactor system.
This system has now been adopted as a joint development project by the members of the European Nuclear Energy Agency.

5

A new design of pool reactor has been produced by G.E.C. and Simon-Carves working in close collaboration with the Imperial College of Science and Technology in London. This collaborative approach has resulted in a reactor ideally suited to meet the specialized experimental and training requirements of universities and colleges.



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Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION

MARCH 1960 VOLUME 5 NUMBER 47

VIEWPOINTS *letters to the Editor*

General Dynamics

SIR: In your Chart of the World's Reactors appearing in the January issue of NUCLEAR POWER, in the Power Reactor summary, the General Dynamics High Temperature, Gas-cooled Reactor (HTGR) to be built on the system of the Philadelphia Electric Company is listed as being AEC-owned; the principal contractor is listed as 'HTRDA.'

The HTGR plant will be owned and operated by the Philadelphia Electric Company. The entire cost of construction will be borne by Philadelphia Electric with the support of the 52 other US electric utility companies comprising High Temperature Reactor Development Associates, Inc., under a fixed-price $24·5 million contract. Prime contractor as engineer-constructor of the plant will be Bechtel Corporation, with General Dynamics having responsibility for the nuclear steam supply system, including the reactor.

In the portion of the chart listing Low Power Research Reactors, reference is made in the 'pool' reactor section to a 10-kilowatt reactor at Cornell University. The Cornell reactor is an above-ground, bulk-shielded, solid homogeneous, TRIGA reactor, supplied by General Dynamics, and it will operate in late 1960 or early 1961.

Manager, Public Relations and Advertising, General Atomic Division of General Dynamics Corporation, San Diego DOUGLAS M. FOUQUET

Dosimeters redefended

SIR: With reference to Mr. Mathias's letter in your January 1960 issue, I would like to reply to his points:

1. The operator can of course read the dose at any moment. It does not follow that the dose will have changed between his readings. It is surely this ability to know whether some unforeseen dose has arisen above the expected value which gives the operator such a sense of security. If he reads it frequently enough, he is unlikely to find that the dosemeter has gone off the scale. In any case, in similar circumstances a film badge would have gone very black indeed and the operator would not know about it for many days. I do not suggest that dosemeters should be the only method of determining safe doses, any more than I would suggest film badges alone should be used. Mr. Mathias is quite right in suggesting the use of dose-rate monitors.

2. I can only say here that accidents do happen and it is better to have a sense of security. Mr. Mathias says in his first paragraph that a relatively large dose is not as uncommon as it should be.

3. Mr. Mathias mentions among the disadvantages of quartz fibre electrometers that no permanent record is available as with a film badge. Surely, however, at some point one must trust the individual to write down a correct reading. Deliberate false readings can be obtained as easily with a film badge as with the instrument, and there is no reason to believe that inaccurate readings due to damage to the instrument are likely to be a serious difficulty. Film processing and assessing of the results is not necessarily more reliable than the rather simpler method of recording and recharging a pocket dosemeter.

On the question of cost I think Mr. Mathias answers his own point, namely that the pocket dosemeter pays for itself in two years. They do, in fact, last 6 years at least.

I certainly do not want to give the impression that I think that pocket dosemeters should *supersede* film badges, only that they should be at least permitted on an equal footing. The user would then have a choice of either system and it would be very interesting to see which he would eventually adopt.

Assistant Director, Research Stewarts and Lloyds Ltd., Corby, Northants J. S. BLAIR

The EDITOR *regrets that correspondence on this subject must now cease.*

Eurochemic Company

SIR: I would like to point out that in the article by Monsieur Huet in your January issue, the paragraph immediately following the mention of the 'Dragon' project (page 81) refers to the *Eurochemic* Company for processing irradiated fuel (another of ENEA's joint European projects) but unfortunately the word 'Eurochemic' has been omitted.

European Nuclear Energy Agency Paris BRUCE M. ADKINS

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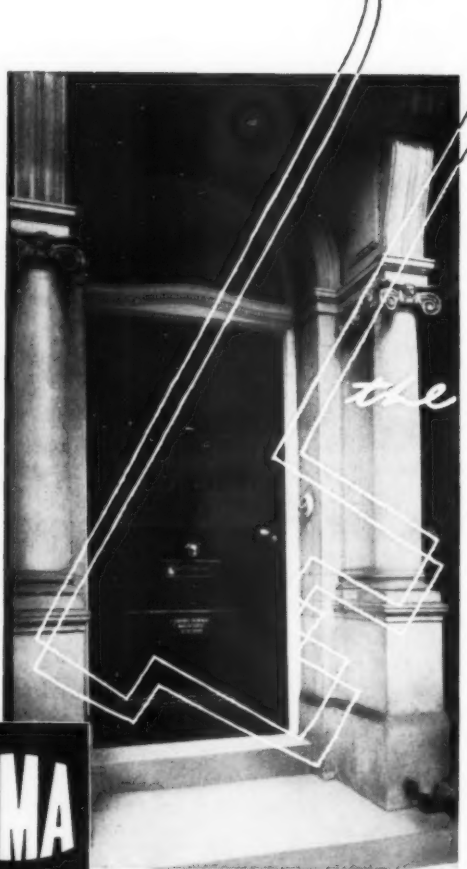
As we see it, a technical journal has two phases of usefulness, the first on immediate publication and the second for retrospective research.

Over the period of a year, a considerable amount of information is published in NUCLEAR POWER, much of which is of permanent reference value to the people engaged in the industry. A detailed key to this information is necessary, however, if the full value is to be gained. Our indexes for the first three years have been modest ones but the index for 1959 has been made far more comprehensive and now includes new products, industrial news, and world activities among other things. The articles of contributing authors are entered under their names as well as by subject. The 1959 index is included in this issue, following the end pages, and is easily detachable.

ask SIMA



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OPINION

Is Dungeness necessary?

IN A FEW WEEKS bids from the three industrial consortia for the Central Electricity Generating Board's proposed 500 MW nuclear power station at Dungeness will go in and a contract is likely to be placed in June. Tenders for the station after this—a 550 MW plant at Sizewell—have already been invited and will be presented in the Summer for a decision towards the end of the year.

The two stations will bring the total nuclear capacity in the United Kingdom up to about 3000 MW. This is only just over half of the 5000–6000 MW target for 1966 and many people in the industry now have serious doubts about Government and CEGB intentions of meeting it. Their uneasiness is not diminished by the fact that the programme was a statement of intention only and in no way binds the authorities. It is very obvious that if a top-level decision is being quietly made to cut the programme down, an official announcement is urgently needed and should be given soon.

It is known that the Chairman of the CEGB, Sir Christopher Hinton, is under heavy pressure from his advisers to delay construction still further. Being one of the men principally responsible for the development of atomic energy in this country, he is unlikely to yield easily; but the opponents of the present official programme have some cogent arguments. The Calder Hall-type magnox stations, after looking at first even more promising than had been expected, seem to be reaching the limit of their development capacity, and though they are within striking distance of competing with conventional power stations, it seems very likely that the gap will not be closed. If the stations are not economic, there remains the case for building them on the grounds that they will help develop technology and gain operating experience of nuclear power stations. But will the stations after Trawsfynydd really teach us much more than we can learn from the first five?

The arguments for continuing with the original programme are well understood, and if the fast reactor proves successful we may yet need all the plutonium we can get. Also the atomic energy industry must be given enough work to keep it together. It has taken some severe knocks in the last year or two and the original five groups have had to shrink themselves to three.

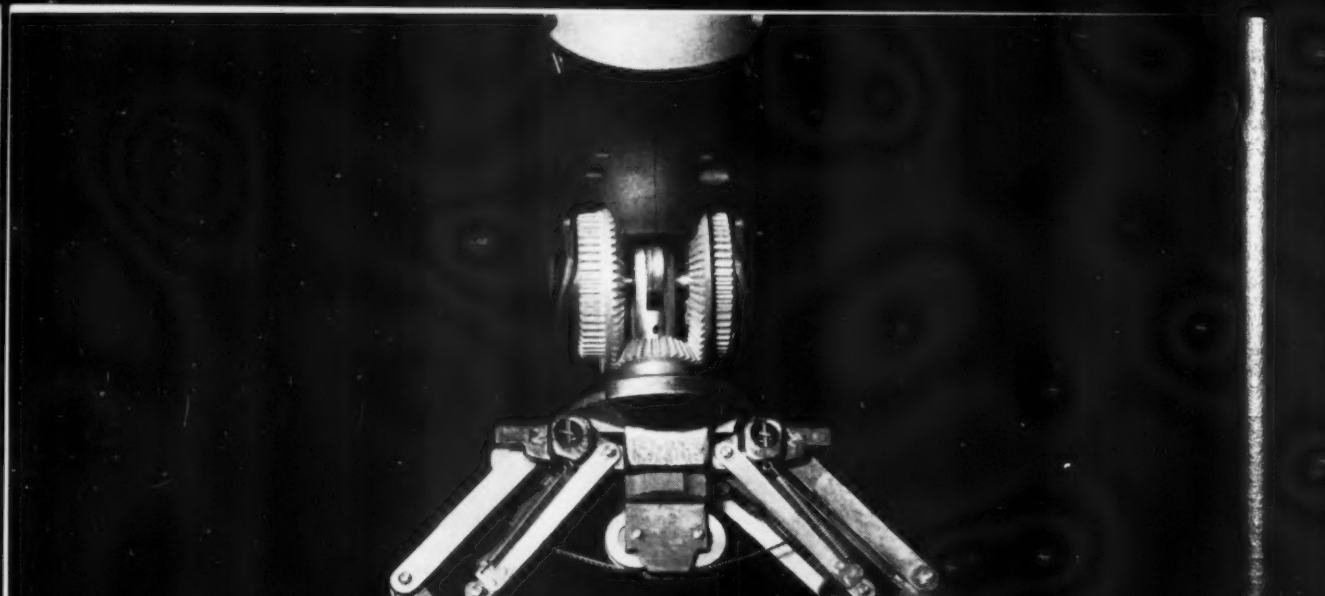
In these circumstances, many thoughts have been directed to the possibility of an early switch to the advanced gas cooled reactor. Consent for a site for a 1000 MW station at Oldbury is expected soon and it is being widely assumed that this will be an advanced design; yet here again the authorities are in difficulty. The CEGB would not be happy to invite, nor the groups to offer, tenders for this type before awaiting experience with the 28 MW experiment now being constructed at Windscale. This will not go into operation until next year and to wait, allowing for even a minimum period of operating experience, would mean delaying the placing of a contract for a CEGB station until the middle of 1962.

It has been urged in some quarters that it is unnecessary to wait so long. After all, some of the first round stations were ordered before results were available from Calder Hall; why should it be necessary to delay now? To see some reasons for this it is only necessary to reflect on the wide divergence of views even on such an essential topic as the material to be used for canning the fuel elements. The results of various experiments on beryllium last year have lowered the temperature of the Atomic Energy Authority's enthusiasm for this material, and though heavily committed to its ultimate use, they are now proposing to start off with stainless steel in the Windscale experiment. The CEGB have never liked beryllium, mainly because of its toxicity. But stainless steel has its snags too. If the cans are too thick, excessive absorption of neutrons could bring the cost of power from AGR's to more than that from the latest designs of magnox stations. After plumping for its use, largely on the results of experience gained in chemical plants, the experts are now realizing that the difficulties of welding very thin-walled tubing, and its weakness and low irradiation life when constructed, may keep the thickness up to uneconomic levels.

There is no indication that the magnitude of these materials problems is being underestimated, but they could be serious enough to lead the whole nuclear power programme into an impasse and they must be given even more attention and more money. Alternatively, ideas such as graphite-backed metallic cans are now in the air and they must be investigated with the utmost urgency.

The CEGB could also consider whether it is really doing all it should for the latest technology of power production. Its initial programme surprised the world and showed a determination to develop it to the full. But does the present slow rate of building indicate that it has lost faith in the magnox stations, and if so is it doing all it can to advance the prospects of other systems—which could provide the small reactors it must soon have when the base-load generating capacity is met and incidentally help the export market?

There is nothing to prevent the CEGB from spending some money by placing its own development contracts in industry—even going as far as reactor experiments and prototypes. Its own work has been hampered by lack of facilities and it is good to see that the plans for the research laboratory at Berkeley are being pushed forward rapidly; work may start there by next October. It is no secret that the CEGB sometimes finds the tutelage of the Atomic Energy Authority a little irksome and it certainly plans to make Berkeley eventually the main research establishment for generation by nuclear power in the country. But the Board should now consider whether its existing plans go far enough and deep enough.



Manipulators

The manipulators used at atomic establishments have to operate under exacting conditions. They are constructed of stainless steel and Kanigen plated aluminium and the plate serves two functions. It resists corrosion and, because of the smoothness of the finish, it also assists in decontamination of the component parts from radio-active material; and the combination of stainless steel and Kanigen plated aluminium reduces the electro potential difference between the component parts. These manipulators, manufactured by Savage & Parsons Ltd., are supplied to users all over the world. Kanigen is used on the aluminium parts of the Tong End assembly and the Master Hand assembly.

Kanigen

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Electrical resistivity	60 microohm cm.
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Coverage	Extremely uniform

Kanigen can be applied to all ferrous metals, aluminium, copper and brass. The plating plant at Oldbury has now been extended, two extra plating tanks are in operation and enquiries for jobbing plating are welcomed. Full information is available on request.

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KANIGEN

Worldview

the month in atomic energy

Third expert on the way

The UK industrial consortia will soon have a chance to sell a Calder Hall-type reactor to Brazil. Kennedy and Donkin Ltd., the consultant engineers, have been asked by the Brazilian Atomic Energy Commission to prepare specifications and invitations to tender for a 150 MW station. These will go out in about six months and the present plan is for building to start within two years on a site 15 miles north of Parati, between Rio de Janeiro and Sao Paulo.

The Brazilian Government has given permission for the project to go ahead providing that the necessary money can be found outside the country. It is understood that the World Bank has grown cooler towards nuclear power projects and is unwilling to finance the scheme, but negotiations with European banks look promising.

Though the Brazilians have some preference for a British-type natural uranium station in view of their own mines, other types are also being considered and American firms may be invited to tender.

Will the Navy be first ?

Inside and outside Parliament over the past weeks the subject of nuclear propulsion for Royal Navy vessels has been discussed at length. When the Civil Lord of the Admiralty, Mr. C. I. Orr-Ewing, recently visited the Admiralty Reactor Test Establishment, Dounreay, which will not be completed for another two years, he said that it was of the utmost importance for the work in this field to be speeded up. A few days later, Mr. Orr-Ewing stated that a report on the possibilities of installing nuclear plant in surface warships would be placed before the Board of Admiralty in the course of the next six months and that the work at Yarrows and Dounreay were being coordinated.

These observations were followed by the Government's White Paper on Defence in which it was stated that the placing of an order for the first all-British nuclear submarine was expected during 1960. This, like HMS *Dreadnought*, at present under construction and expected to be launched this year, will be of the 'hunter' or 'anti-submarine' type. In the Navy Estimates presented the day after the white paper, Lord Carrington, the First Lord of the Admiralty, pointed out that the increased provision for new ships included more money for nuclear submarines which also accounted for most of the 10% increase in research and development expenditure.

On the mercantile side, the Minister of Transport, Mr. Ernest Marples, has indicated that following the findings of the Galbraith Committee (see *Worldview*, January) tenders for OMR's and BWR's suitable for a 65,000 dwt tanker had been requested from five groups. These groups are English Electric, Hawker Siddeley Nuclear Power Co., Babcock & Wilcox Ltd., AEI-John Thompson of the Nuclear Power Group and the Mitchell-Fairfield-Combustion Engineering Nuclear Power consortium.

ARGONNE'S LATEST The Argonne Fast Source Reactor is now in full operation. Mr. F. W. Thalgott, left, a director of Argonne's Idaho Division, was responsible for the design of this facility

While it is anticipated that some months will pass before tenders are submitted to the Ministry of Transport and that construction is likely to take some four to five years, the General Council of British Shipping has set up a committee to consider the formation of a suitable group to own and operate the vessel. Already the British Shipbuilding Research Association and the AEA have cooperated in the design study for a land-based prototype marine plant.

Vickers to make Trigas

The Triga research reactor may soon be made in the United Kingdom under a new licence agreement. Signed by Vickers-Armstrong and the US General Dynamics Corporation, it covers both manufacture and sale in the United Kingdom. The standard Mark I (below ground) and the Mark II (above ground), both operating at a maximum steady set level of 100 kW thermal, will be available at 'under £100,000 including fuel.' These Trigas are solid homogeneous reactors with a graphite reflector, fuelled with U/Zrh alloy (20%) aluminium-clad, in rods.

Vickers-Armstrong believe that there is a potential market for these reactors in most of the larger universities and already they have had several firm enquiries.

Triga reactors now in use or under contract total 15. They have been bought

DELIBERATE ACCIDENT To evaluate the subsequent medical treatment, the uncontrolled run of the zero power reactor at Vinca, Yugoslavia, is to be repeated. Under formal agreement the IAEA are carrying out a dosimetry experiment. Seen at the signing of this agreement by IAEA's Director General, Mr. Sterling Cole and Mr. Slobodan Nakicenovic, Yugoslavia's Under Secretary of State, are, left to right, Mr. Drago Baum of the Yugoslav Nuclear Energy Commission; Mr. J. Snizek, Director of IAEA; Mr. P. C. Szasz, IAEA; Mr. G. W. C. Tait, Director of IAEA; Mr. H. de Laboulaye, Deputy Director General, IAEA; Mr. H. D. Brown, IAEA; Mr. R. Barker, IAEA

WORLD'S FIRST The 25 GeV proton synchrotron at the CERN site, near Meyrin, Geneva, was inaugurated on February 5 by Professor Niels Bohr. Seen at the ceremony are, left to right, Professor Niels Bohr; Professor E. M. McMillan, USA; Mr. M. F. de Rou, President of CERN; and Professor R. Oppenheimer, USA. Below is part of the system of 100 magnetic blocks

by: John Jay Hopkins Laboratory; University of Arizona; University of Lovanium; Veterans Administration Hospital, Nebraska; World Agriculture Fair December 1959–February 1960 (On lease to USAEC); National Committee for Nuclear Research (CNRN); University of Illinois; Cornell University; Kansas State University; University of Minas Gerais; Federal Ministry of Education, Atominstitut, Austria; Republic of Korea; Musashi College of Technology, Japan; Rikkyo (St. Paul's) University, Japan; and the Republic of Viet Nam Nuclear Institute.

Most of these will be used for training, research, and isotope production, but Dr. de Hoffman, President of General Atomics Division of General Dynamics and pioneer of the design believes that there is considerable potential for Triga as an industrial tool, particularly in chemical analysis. With its inherently safe homogeneous fuel elements, it could be used by unskilled operators.

One of Vickers staff is at present in San Diego with General Dynamics and it is hoped to build a Triga at Vickers' Swindon works from all-British components.

The biggest yet !

The Minister of Power has given his consent to the Central Electricity Generating Board to build a 650 MWe plant at Sizewell in Suffolk (completion of which is scheduled for 1965). The CEGB has requested tenders for plant with a guaranteed output of 550 MWe from the consortia for this nuclear station, the sixth in the Board's programme and it is hoped that the contract will be placed by the middle of this year. Essential road work and site clearance on just over 200 acres of land are already in hand.

The CEGB are now seeking consent from the Ministry of Power to proceed with the building of a 1000 MWe station at Oldbury in Gloucestershire.

INTERNATIONAL

Scant hope for nuclear energy

Paris—Over the past weeks, Europe's future power requirements have been the subject of a number of reviews. The OEEC Energy Advisory Commission's report 'Towards a New Energy Pattern in Europe' states that as there is no indication of any shortage in power production by conventional means between now and 1975, nuclear projects should be reorientated. While the construction of nuclear power plants should be cut back, considerably more emphasis and effort should be devoted to research. In this way commercial competitiveness might be achieved by the middle 1970s.

Aimed at achieving economic cooperation, another conference of twenty nations, in Paris, has praised the work of OEEC in maintaining a policy directed to the sound use of economic resources. A further conference is to be held in April by the same OEEC member countries to consider proposals for an 'improved organization for economic cooperation' between them.

Watching radiation

Vienna—The IAEA has awarded 47 research contracts to scientific institutes in twenty countries and to one international organization for research on radiation safety and protection, radioisotope applications and methods of applying safeguards against the diversion of nuclear materials to non-peaceful uses. Agency-supported research projects on low-level and immediate radiation effects have been given to institutes in Austria, Netherlands, Poland, Switzerland and the United Kingdom. Initially, contracts for the study of non-destructive analysis of irradiated fuel elements were given to Belgium, France and the United States and now Poland, Norway and the Federal Republic of Germany have been asked to join in this work. The total expenditure by the Agency on these projects is some $400,000.

AUSTRALIA

Hifar progresses

Lucas Heights—Full power operation with this facility has now become possible and the first experimental test loops are being installed. The initial work for which Hifar will be employed will be the production of short-life isotopes such as gold and phosphorus for medical purposes here. These have, so far, not been available due to remoteness from overseas sources. Large scale production of isotopes is envisaged and eventually the Australian Atomic Energy Commission may supplant the AEA in the Southern Hemisphere for the supply of large sources such as cobalt-60.

AUSTRIA

Another fuel grouping

Vienna—The State-owned organization, Oesterreichische Stickstoffwerke at Linz, have joined a British company, Rio Tinto Management Services (UK) Ltd., and a German firm, Degussa AG, to form a new concern Austro-Chematom. The company has been established to undertake the production of fuel elements and, by its international composition, will be in a favourable position to supply the Inner Six and Outer Seven European

countries and possibly, the British Commonwealth. The necessary uranium concentrates are to be supplied by Rio Tinto Services.

BRAZIL

New processing plant

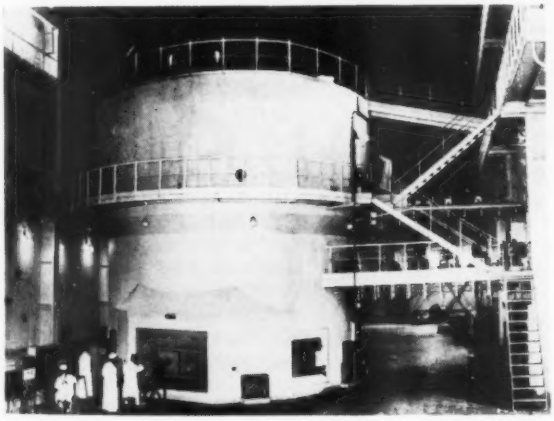
Rio de Janeiro—A new processing plant is being constructed at Poços de Caldas, in the state of Minas Gerais. It will have an estimated capacity for treating some 200,000 tons of zirconite to yield 60 tons of pure uranium sodide annually.

CANADA

Looking further afield

Toronto—Following his criticisms of the present state of nuclear engineering in Canada, Mr. Winnett Boyd, the reactor designer, has looked to the US to further his plans. An agreement has been concluded with Arthur D. Little, Inc., industrial research consultants, of Cambridge, Mass., to develop the Daniels-Boyd nuclear steam generator, D-BNSG. Capable of generating 400 MWe, this plant it is proposed, would use a spherical pressure vessel, uranium monocarbide fuel and helium as the coolant, to produce steam at a temperature of 1050°F and a pressure of 2400 lb/in².

A feature of this design is the horizontal arrangement of the ceramic fuel elements combined with the vertical cooling flow. Based on accepted US standards, it is expected that this type of reactor would be capable of producing electricty at a cost of 6·3 mills per kilowatt-hour.



New research centre

Chalk River—A site of some 11,000 acres on the east bank of the Winnipeg River, 60 miles ENE of Winnipeg, Manitoba, has been selected for Canada's second nuclear research centre (see *Worldview*, December 1959). To be known as the Whiteshell Nuclear Research Establishment, it will start as a small unit but, eventually, it is expected to be as large as that of the Chalk River plant. Work will commence on the site during the summer under the control of the Shawinigan Engineering Co. Ltd., but the building of a major facility is not anticipated to start until 1961.

Redeployment of fuel potential

Montreal—Although the Government has not yet reached any conclusions in their efforts to gear Canadian fuel output to the changing and more competitive world conditions, private industry is consolidating its resources. The Rio Tinto Mining Company of Canada Ltd., is to amalgamate the Algom Uranium Mines Ltd., Milliken Lake Uranium Mines Ltd., Northspan Uranium Mines Ltd., and Pronto Uranium Mines Ltd., who will pool their uranium oxide contracts with Eldorado Mining & Refining Ltd., the Canadian Crown Corporation. The amalgamated company will be known as Rio Algom Mines Ltd., and will possibly take-over contracts from a number of other uranium producers.

Another company active in the nuclear fuel field is the Peace River Power Development Co. Discussions are taking place with interested groups in the UK on the possibility of setting up a diffusion plant to produce enriched uranium. Utilizing the estimated one million horsepower of cheap hydro power on the Peace River, it would enable fuel to be produced at prices competitive with those of the United States.

Large order for the UK

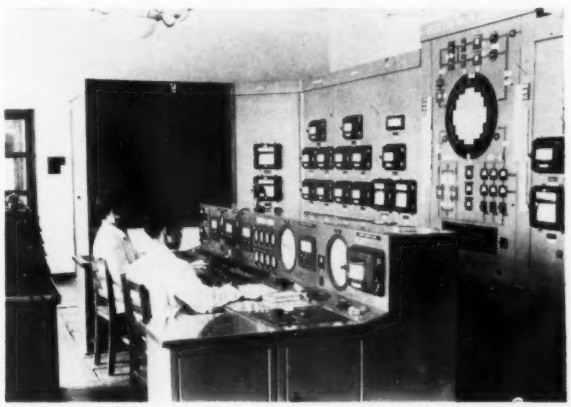
Montreal—The Canadian organization of AEI has obtained a £M2 contract for the supply of a 220 MW turbo-generator for the Candu project. The turbine will be built in the United Kingdom while the generator, in the main, will be constructed in Canada by the Canadian GEC with whom the AEI has a working arrangement.

EURATOM

The 'Six' to have Embassies

Brussels—To coordinate policies and maintain relations between the UK and the US and the executive bodies of the European Community it is proposed to set up Embassies in London and Washington. These diplomatic envoys will represent the Commission of the European Economic Community (the Common Market), the Commission of the European Atomic Energy Community (Euratom) and the High Authority of the European Coal and Steel Community.

The work of Euratom was recently reviewed by the Scientific and Technical Committee of the European Community when it noted that the Italian Government's failure to ratify the Ispra research agreement was 'proving a great detriment to the Community.' On the Orgel project, involving the study of a heavy water moderated reactor with organic liquid cooling, the committee reviewed the information being received from Canada and the UK as well as its own data from France and Germany and stated that the eventual construction of such a reactor would provide worthwhile experience for the Community's nuclear industry.

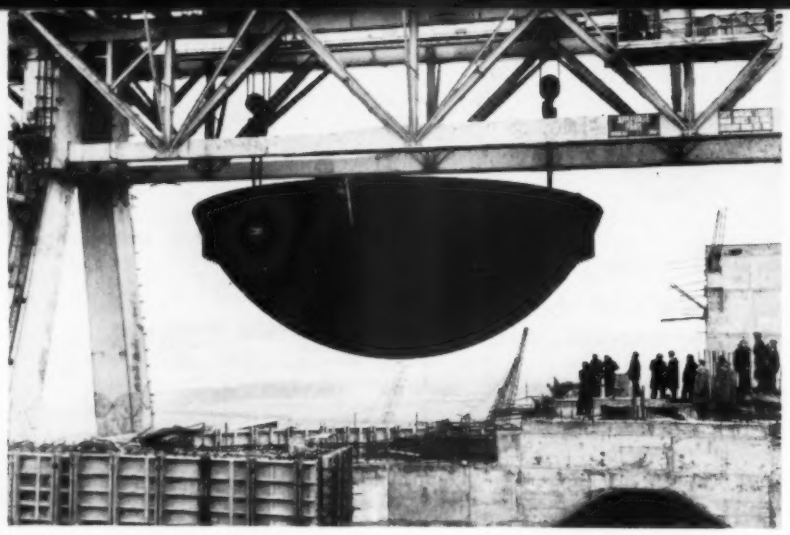


CHINA'S FIRST This USSR designed 10 MW heavy water research reactor is now in operation at Pekin

GERMANY

One law for all

Bonn—Replacing the provincial governments' interim laws, the Federal Government has now brought into force the 'German Atomic Law' for the economic uses of nuclear power and this follows closely the proposals of OEEC's Liability Convention. Among the provisions of the new law, the essential points are the encouragement of research and development; radiation protection and compensation; protection of Federal Germany



UK POWER STATION PROGRESS Making up for lost time at **Hunterston**, the complete bottom head and support course of the first reactor vessel, left, has been placed in position. At **Bradwell**, below, overall civil construction is nearing completion and all the heat exchangers are being connected up. At **Berkeley** the second 1000 ton reactor vessel has been successfully stress relieved

from internal or external security dangers due to nuclear energy; and to guarantee the Government's international liabilities in the nuclear field.

Licensing requirements are also included and cover not only the constructors and operators of reactors but anyone making or handling active materials. The licensing authority is also responsible for defining the nature and amount of insurance applicable and the assessment has to be re-made every second year so that any changes that have occurred may be taken into account. The Government can be called upon to meet compensation claims of up to 500 million DM for any one occurrence at installations brought into service prior to December 31, 1970. This new law also sets out the penalties for non-compliance which include a maximum of ten years imprisonment for anyone exposing personnel to harmful irradiation.

With the introduction of these measures, the earlier local laws are annulled and only licences already granted by the different 'Bundesländer' remain valid.

GREENLAND

Providing economic power

Copenhagen—An American plan to build a 1½ MWe power reactor in Greenland has been approved by the Danish Government. Prefabrication will be largely used and the plant is scheduled to be in operation by the coming autumn. It will be located at the new US base 'Camp Century' some 100 miles east of the coastal base at Thule on the west coast of North Greenland. Due to the high cost of transporting conventional fuels in this location it is anticipated that this installation will be the first nuclear power station in the world to operate economically.

ITALY

Power output to be boosted

Rome—The joint Euratom-US committee, examining proposals under the co-operation agreement, have accepted the Società Elettro-Nucleare Nazionale, SENN, 150 MWe BWR project to be built at Punta Garigliano. At the same time the committee asked SENN to increase the plant's output up to 230 MWe and this has been accepted in principle. It is anticipated that in a few years' time, following a full research and development programme, not only will it be possible to implement this uprating of power but, at the same time, it will be possible to bring about an appreciable reduction in the cost of the power produced.

New OMR project

Milan—As part of the five years' plan of the Comitato Nazionale per le Ricerche Nucleari, CNRN, a 30 MWt OMR is to be designed and built. AGIP Nucleare will be responsible for the design and the fabrication will be carried out by Fiat and Montecatini (SORIN) under a programme to be known as PRO. It is anticipated that other Italian companies will also participate in this project which will initially employ uranium oxide fuel elements coated with sintered aluminium powder.

Strong grip on industry

Rome—The Council of Ministers have announced that a new draft of the law on the peaceful uses of atomic energy has been drawn up for Parliamentary approval. One of the new proposals reserves for the state all industrial activities in the fields of the production and treatment of enriched fuels. Further, it has been considered expedient to bar private enterprise from engaging in electro-nuclear power production until it has been decided whether or not all electricity production is to be nationalized.

Another marine tie-up

Trieste—An agreement has been signed by the US Babcock & Wilcox Company and the United Shipyards of the Adriatic, Cantieri Riuniti Dell'Adriatico, which enables the Italian company to build and sell merchant vessels powered by B. & W.-designed plants. This arrangement will be effective for ten years, commencing January 1, 1960, and will cover ships built for the Italian merchant navy or for operators based outside Italy.

SOVIET UNION

Research in the Far East

Moscow—The Siberian branch of the USSR Academy of Sciences has approved a scheme, estimated to cost some 10,000

million roubles, to construct a series of research institutes in Siberia and the Far East. Among the locations included in this scheme, large research facilities will be established at Novosibirsk, Irkutsk, Krasnoyarsk, Vladivostok, Khabarvsk and Chita.

WORLDBRIEFS

• **International** France has donated a consignment of nuclear electronic equipment to the IAEA and a second consignment is expected to arrive in Vienna during March. Total value of the equipment is some $30,000.

• **IAEA** Two expert panels held meetings during February to establish international regulations for the transport of radioactive materials. One panel covered isotopes and low activity materials and the other reviewed the problems in moving large radiation sources.

• **IAEA** Following the first reading of the safeguards provisions against diversion to non-peaceful purposes of materials or other assistance provided by the Agency, a working committee is now detailing the scope and methods of implementing these provisions.

• **Australia** The Atomic Energy Commission is pressing the Government to introduce a single set of laws to control the use of radioactive materials so that a long term programme can be pursued without interference from different State controls.

• **Austria** The Government has approached the IAEA for possible supply of six kilogrammes of 90% enriched uranium-235 which will be required in the future for refuelling the 5 MWt reactor at present under construction at Seibersdorf.

• **Czechoslovakia** The cyclotron at the Nuclear Physics Institute at Rezi was brought into operation on February 18. It was supplied by the USSR and is the first unit in use in the country.

• **France** An industrial pilot plant for the production of heavy water has been brought into operation at Toulouse. It has an estimated output of between 1½ and 2 tons per annum.

• **Germany** The 50 kW liquid homogeneous research reactor, BER, in West Berlin, is now in full power operation and is being used by the Hahn-Meitner Institut für Kernforschung.

• **Holland** The Government has made arrangements with the Euratom commission for a Euratom research centre to be established at Petten adjacent to the existing Dutch facility.

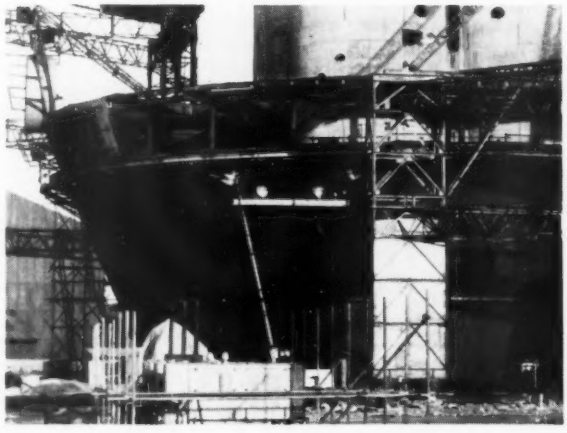
• **Holland** An overall Nuclear Energy Bill has been submitted to the Lower Chamber of the States-General. It covers licences, transport, irradiation protection and recommends the setting up of a Nuclear Council to deal with the scientific, technical, public health, foreign relations and legal aspects of nuclear activities.

• **India** The Director General, Mr. Sterling Cole, and two Deputy Directors General of the IAEA, made a ten-day visit to India during February. As well as visiting the Indian atomic energy establishment at Trombay, near Bombay, they visited the locations on the Travancore coast where thorium is extracted from the mineral sands.

• **India** A high-level radiation laboratory is to be built at Trombay by Vitro International at a cost of $M4.

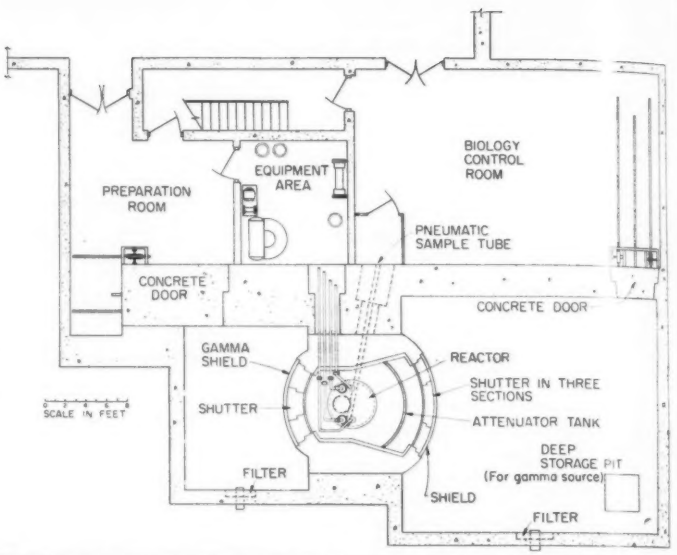
• **India** The first research grant under the Exchange and Training Programme of the IAEA has been awarded to Dr. R. P. Agarwala to undertake 12 months research at the Massachusetts Institute of Technology.

• **Israel** An international conference 'Science in the advancement of New States' is to be held at the Weizmann



THE NEXT STEP Work on the 28 MW advanced gas cooled reactor experiment at Windscale is now going ahead night and day

THE JANUS REACTOR This facility is shortly to be constructed at the Argonne National Laboratory for biological research, and is unique in that it will have two radiation faces. It is basically a heterogeneous tank type and fuelled with 6·6 lb of uranium 235, and designed to operate for extended periods of time at power levels between 1 and 200 kW. The two faces will provide different levels of irradiation; from one, specimens will be exposed at a dose rate of approximately 100 rads per minute; and from the other, the dose rate will be of the order of from 0·1 to 50 rads per week



Institute at Rehovoth during the second half of August 1960.

• **Italy** The Government, after much delay, has ratified the OEEC's Eurochemic statutory convention and subscribed to 44 shares for the processing plant at Mol, Belgium.

• **Italy** Plans to build the SELNI 'Enrico Fermi' 165 MWe PWR power plant on the Ligurian Riviera of Levante in the vicinity of Vallegrande have now been submitted to the Italian Ministry of Industry for approval.

• **Japan** Dr. T. Ippon Matsu, vice-president of the Japan Atomic Power Co., is at present in the UK on a three-week visit for further discussions with AEA on fuel supplies for the Tokai-Mura power plant.

• **New Zealand** Highly radioactive mineral has been found in the Buller Gorge on the west coast of South Island. Drilling operations are to start shortly.

• **Pakistan** On their return journey from India, Mr. Sterling Cole and the two other senior IAEA officials visited the Pakistan atomic energy centre.

• **Russia** The experimental reactor of the Ukrainian Academy of Sciences' Institute of Physics at Kiev achieved criticality on February 12.

• **Spain** Built by the State Junta for Nuclear Power, a plant at Adujar for the processing of uranium ores has been inaugurated by General Franco.

• **United Kingdom** A small breeder facility design study, the Zebra, zero power breeder reactor, is being considered by the AEA but so far no Treasury approval has been received to proceed with this project.

• **United Kingdom** The Government has set up an Industrial Development Office in New York to provide information on the establishment of manufacturing enterprises in Britain.

• **United Kingdom** Discussions now taking place within the AEA are expected to lead to a fall in the export price charged for natural uranium fuel elements from the present figure of £20,000/tonne to about £17,000/tonne.

• **United Kingdom** To train reactor operators for the CEGB and SSEB a special purpose computer, built by Short Bros and Harland Ltd., is to be installed at the AEA's Calder Hall Operations School.

• **United Kingdom** A new low priced 10 kW research reactor, the Consort, is to be marketed by The General Electric Company Ltd. The first of this type is expected to be installed at the Imperial College.

• **United States** The core for the NS *Savannah* has gone critical in a land test rig.

• **United States** AMF are to design and build a 5 MW heterogeneous heavy water moderated research reactor for AEC's Ames Laboratory. Construction will start later this year and completion is scheduled for 1962. It will have provision for the power to be eventually uprated to 10 MW or more.

• **United States** The US Navy's first nuclear propelled aircraft carrier, the USS *Enterprise*, is scheduled to be launched on July 15, 1960. It will be powered by eight Westinghouse A2W reactors and have a loaded displacement of 85,000 tons.

• **United States** As part of the Advanced Epithermal Thorium Reactor programme, Atomics International are to build a new research facility at Santa Susana Mts., near Los Angeles for Southwest Atomic Energy Associates.

• **United States** The Shippingport PWR was refuelled in February for the first time by the Duquesne Light Co., for the AEC. The first set of fuel elements operated for a total of 5806 full power hours which was 2806 hours greater than the design life.

• **United States** Two representatives of the British Shipbuilding Association, one from the Italian Ansaldo shipyards and one from the French Atomic Energy Commission have taken part in the Foreign Observer programme organized by the Maritime Adminstration in conjunction with the NS *Savannah*.

• **United States** Led by Sir William Cook, an AEA team visited the Argonne National Laboratory when the EBR-II was inspected.

• **United States** Atomics International have completed and installed the second 50 kW reactor core in the Kinetic Experiment on Water Boilers, KEWB, facility at Burro Flat Field Laboratory.

• **United States** The AEC has made available for public use a further 78 patents owned by the Government and held by the Commission. Non-exclusive, royalty-free manufacturing licences covering these patents can be obtained.

This first of two articles reviews the slowly accumulating data on changes in tensile properties

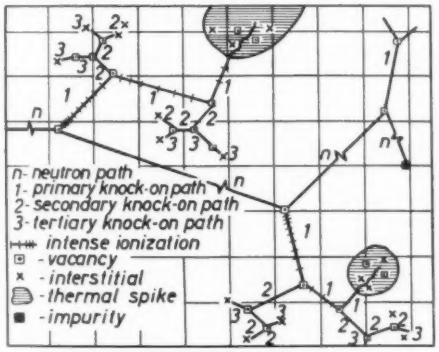
Radiation damage in iron and steel

by D. R. HARRIES, B.Sc., Ph.D.
Metallurgy Division, AERE, Harwell

BRIEFLY, the effects of neutron irradiation are to increase the yield and ultimate tensile strengths and to decrease the elongation and reduction of area values in tensile tests; to increase the ductile-brittle transition temperature and reduce the ductile energy absorbed values in notched-bar tests; and to increase the hardness. It is hoped that sufficient data is given here to illustrate the principal effects of irradiation on the behaviour of steels.

Mechanism of radiation damage

Neutrons may cause radiation damage in reactor structural materials in two ways: (a) directly by knocking atoms out of place in the lattice creating vacant sites and interstitial atoms, i.e., by scattering; (b) indirectly by producing changes in atomic nuclei creating impurity atoms, i.e., by absorption.



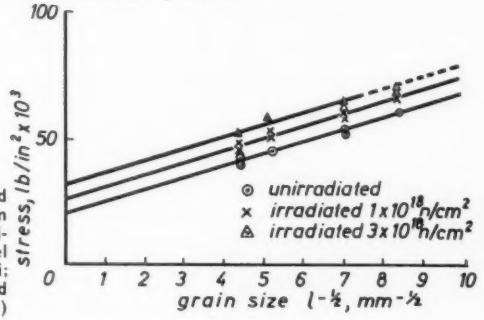
This sketch shows the five principal mechanisms of radiation damage. Grid-line intersections are equilibrium positions for atoms (Fig 1)

Although neutrons of all speeds are scattered by nuclei, only the fast ones freshly created from nuclear fission produce radiation damage by scattering because only these are capable of giving a large recoil energy to the struck nucleus. The energy transferred by a 2 MeV neutron in a head-on collision with an iron nucleus is about 0·14 MeV. The energy required to displace an atom from the lattice creating a vacancy and an interstitial is only about 30 eV and so the displaced atom can displace further atoms by colliding with them. This is illustrated in Figure 1 which shows diagrammatically what happens when a neutron impinges on the surface of a crystal. The 'primary knock-ons' produce large numbers of displacements. Eventually, the neutron is captured by the nucleus of one of the atoms which it transmutes.

Only a small part of the energy of the primary knocked-on atom is stored in the form of vacancies and interstitials. The remainder is released as increased atomic vibrations in a region of about 40 atomic spacings across and containing 60,000 atoms. The temperature in this region rises to about 4000°C and the material behaves more like a liquid than a solid for the time it takes the thermal pulse to disperse (about 10^{-12} s). During this process the point defects in the region of the thermal spike are mostly eliminated and the region freezes back on the surrounding lattice containing only a few quenched-in vacancies and interstitials.

Steels have an outstanding part to play in the nuclear energy programme. They are used in reactors for the pressure vessel, thermal shields, liner tubes for fuel-element channels, pressure tubes, fuel-element canning and control rods. The use of a steel within the primary system of a reactor is dependent not only on the pre-irradiation mechanical properties, corrosion resistance to the coolant, weldability and acceptable nuclear properties, but also on the extent of the property changes induced as a result of bombardment with nuclear radiation.

The theory and mechanism of radiation effects in materials have been described in detail by Seitz (*1*), Cottrell (*2*), and Vineyard (*3*). Radiation hardening in mild steel has been investigated (*4*) (*5*) using the experimentally derived relationship between the yield stress (σ_y) and the grain diameter d (*6*) (*7*): $\sigma_y = \sigma_i + ky.d^{-\frac{1}{2}}$
where σ_i is a measure of the frictional resistance to the movement of free dislocations in the lattice and ky is a measure of the dislocation locking stress.



Variation of yield stress with grain size for a specimen of En2 steel (0·15% C; 12% Si; 0·59% Mn) tested at −78°C (5) (Fig 2)

TABLE I *Neutron irradiation effects on the room temperature tensile properties of pure iron (8)*

INTEGRATED NEUTRON DOSE, n/cm^2 (> 1 MeV)	0·2% P.S., $\times 10^3 lb/in^2$	U.T.S., $\times 10^3 lb/in^2$	ELONGATION, %	R. OF A., %
Unirradiated	13·4	34·6	60	94·0
1×10^{17}	21·0	35·5	53	92·0
2×10^{18}	39·0	42·0	36	92·0
$1{\cdot}5 \times 10^{19}$	44·0	49·0	35	91·6
$1{\cdot}6 \times 10^{20}$	49·5	55·0	34	90·0

Samples of an En2 steel of various grain sizes were irradiated and some of the results are shown in Figure 2. The dislocation locking stress is not detectably changed by irradiation but σ_i increases with increasing neutron dose. This result suggests that irradiation produces dispersed islands of damage that are sufficiently mobile to withstand thermally activated movements of dislocations.

Changes in properties of steels may also be caused by thermal neutron capture and subsequent radioactive decay. For example, some structural steels contain up to 0·007% boron, while control rod steels may contain about 4% boron. The boron-10 isotope in natural boron reacts with a slow neutron to give lithium-7 plus an alpha particle with an energy of 2·8 MeV. This kinetic energy will be dissipated locally in the steel and will displace a large number of atoms. In addition, swelling may result from the helium gas formation. However, with the exception of steels containing boron or any other gas-forming isotope (Li-6, Be-9, and Mg-25) the effects of thermal neutron capture and subsequent radioactive decay can be ignored in relation to the effects produced by fast neutron atom displacements unless the integrated thermal neutron dose exceeds about $10^{22} n/cm^2$.

TABLE II *Effect of irradiation on the yield stress of high-purity iron (8)*

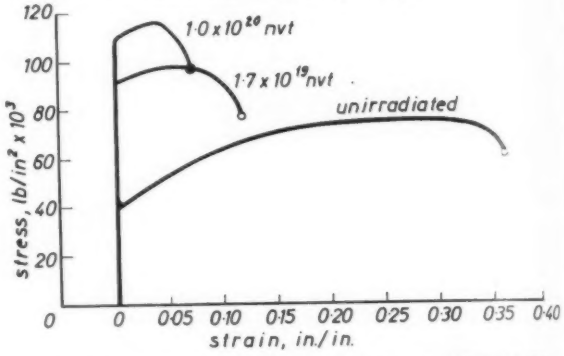
	YIELD STRESS, lb/in^2	INCREASE IN YIELD STRESS, lb/in^2
Unirradiated	13,800	—
$10^{17} n/cm^2$(> 1 MeV) at 80°C	21,600	7800
$10^{17} n/cm^2$(> 1 MeV) at150°C	22,200	8400
$10^{17} n/cm^2$(> 1 MeV) at 300°C	19,800	6000

Tensile properties

Pure iron The effect of increasing neutron dose on the room temperature tensile properties of polycrystalline pure iron irradiated at 80°C are presented in Table I. The yield and ultimate tensile strengths are increased as exposure increases with the yield strength increase approaching saturation at the highest dose. Results show that although the elongation is reduced the reduction in area is essentially unaffected. Most of the changes in elongation take place after an exposure of $2 \times 10^{18} n/cm^2$; and consequently also indicate an approach to saturation. Similar results were obtained by Kunz and Holden (*9*) (*10*) who irradiated single crystals to an integrated thermal neutron dose of $10^{18} n/cm^2$ at 50°C (max.). It was also established that the material became less sensitive to radiation if it was first hardened by plastic working.

The effect of irradiation temperature is illustrated in Table II. The results show that the radiation induced change in yield stress is markedly dependent on temperature and that an exposure temperature of 300°C does not effectively reduce the irradiation effects.

Ferritic steels The effect of neutron irradiation at < 95°C on the room temperature tensile properties of an ASTM A2I2 B steel normalized from 1040°C, is given in Table III. The yield stress is increased more than the ultimate tensile strength and consequently rate of work-hardening is low. After a dose of $1 \times 10^{20} n/cm^2$ the plastic deformation before necking is small. A tenfold increase in the strain rate had little effect on either the unirradiated or the irradiated properties. This type of steel which shows a characteristic yield point in the unirradiated condition does not show one after irradiation (Figure 3).



Conventional stress-strain curves for fine-grain ASTM A212B carbon-silicon steel irradiated at 95°C (max) (12) (Fig 3)

Pravdyuk *et al.* (*13*) have observed that the maximum values of the yield and ultimate tensile strengths of two ferritic steels irradiated at 80°C are reached within the range 2 to 5 $\times$ $10^{19} n/cm^2$ (> 1 MeV). However, the elongation values continued to decrease without reaching saturation even after $1 \times 10^{20} n/cm^2$ (> 1 MeV).

The effects of irradiation at various temperatures on the tensile properties of ASTM A 106 steel have been reported

TABLE III *Effect of neutron irradiation on the tensile properties of an ASTM A2I2 B steel (11). ASTM grain size No. 5. Strain Rate 0·05/min*

DOSE, n/cm^2 > 1 MeV	YIELD STRESS, $\times 10^3 lb/in^2$	U.T.S., $\times 10^3 lb/in^2$	R. OF A., %	UNIFORM ELONGATION, %
0	50·1	75·4	64	22
1×10^{19}	65·4	80·8	68	18
1×10^{20}	94·9	97·1	28	5·4
1×10^{20}	92·6	97·0	24	5·6

TABLE IV *Effect of neutron irradiation on the room temperature tensile properties of fine and coarse-grained ASTM A 106 steel (14)*

STEEL	DOSE, n/cm^2 >1 MeV	TEMPERATURE IRRADIATION, °C	Y.S., $\times 10^3 lb/in^2$	U.T.S., $\times 10^3 lb/in^2$	UNIFORM ELONGATION, %
A 106. Fine grain. ASTM No. 7 (1) Al killed	0	—	40	76	18
	2×10^{19}	305	81	102	8
	2×10^{19}	360	55	87	11
	2×10^{19}	405	48	82	12
	8×10^{19}	305	79	106*	6
	8×10^{19}	415	47	79	11
	1×10^{20}	80	97	102	4
A 106. Fine grain. ASTM No. 2 (2) Si killed	0	—	46	80	14
	2×10^{19}	305	93	115	8
	2×10^{19}	360	67	98	9
	2×10^{19}	405	43	84	14
	7×10^{19}	305	87	103*	3
	7×10^{19}	415	64	94	11
	1×10^{20}	80	116	121	2

* Broke without necking

(2) 0·24% C; 0·72% Mn; 0·20% Si; 0·018% P; 0·023% S.

(1) 0·24% C; 0·70% Mn; 0·19% Si; 0·019% P; 0·020% S.

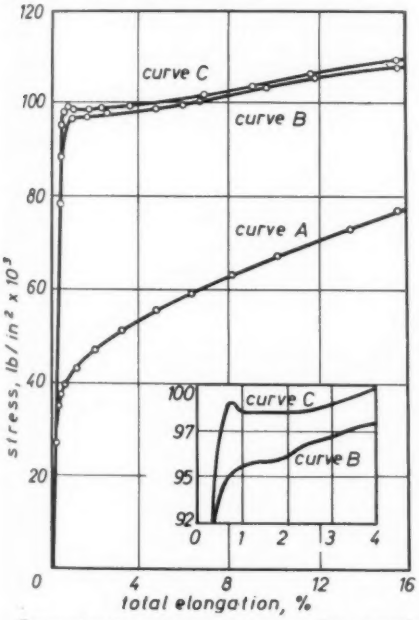
Both steels normalized at 950°C.

TABLE V *Effects of neutron irradiation at 80°, 300° and 600°C on the room temperature tensile properties of austenitic stainless steels (13)*

STEEL*	IRRADIATION TEMPERATURE, °C	INTEGRATED NEUTRON DOSE, n/cm² (> 1 MeV)	U.T.S. × 10³ lb/in²		Y.S. × 10³ lb/in²		ELONGATION, %	
			before	*after*	*before*	*after*	*before*	*after*
1	80	$1{\cdot}4 \times 10^{18}$	93·9	105·2	34·1	62·6	66	55
	300	$2{\cdot}4 \times 10^{18}$	100·9	103·8	37·0	59·7	64	50
	600	$4{\cdot}4 \times 10^{18}$	108·1	108·1	45·5	38·4	62	70
2	80	1×10^{20}	95·3	120·9	42·7	95·3	70	45
	300	7×10^{18}	98·1	112·3	49·8	51·2	60	57
	600	$1{\cdot}1 \times 10^{19}$	108·1	100·9	46·9	39·8	48	51
3	80	5×10^{19}	95·3	126·6	35·6	95·3	50	29
	300	$3{\cdot}7 \times 10^{18}$	96·7	105·2	35·6	41·2	56	52

* Steel 1. 18% Cr; 9% Ni; Ti stabilized. Quenched.
Steel 2. 18% Cr; 12% Ni; 2% Mo; Ti stabilized. Quenched and stabilized at 850° for 2h.
Steel 3. 14% Cr; 14% Ni; 3% Mo; Nb stabilized. Quenched.

by Wilson (*14*) and are shown in Table IV. The fine-grained steel appears to be less sensitive to radiation damage than the coarse-grained steel and this has been confirmed by Churchman *et al.* (*4*). Whereas all the unirradiated samples were ductile, the coarse-grained samples were brittle after a dose of $1{\cdot}5 \times 10^{19}$ n/cm² (thermal) but the fine-grained specimens showed some ductility even after 9×10^{19} n/cm² (thermal). These results also show that exposure at temperatures in excess of 400°C are insufficient to cause complete annealing of the damage. Nevertheless, irradiation at 415°C produces lesser changes in tensile properties than irradiation to the same integrated neutron dose at lower temperatures.



Curve A
Composite curve from two tests on unirradiated metal at strain rates of 0·01 and 0·05 in./in./min

Curve B
Irradiated — $7{\cdot}8 \times 10^{19}$ n/cm² at 95°C (max). Strain rate 0·01 in./in./min

Curve C
Irradiated — $7{\cdot}8 \times 10^{19}$ n/cm² at 95°C (max). Strain rate 0·05 in./in./min

Conventional stress-strain curves for annealed austenitic stainless steel type 347 (11) (Fig 4)

Liashenko and Ibragimov (*15*) found that the tensile properties of two ferritic steels were considerably changed by irradiation at 500–600°C but the electrical resistance was almost unchanged. At such irradiation temperatures it would be anticipated that the fast neutron atom displacement damage would have completely annealed out. However, the changes in properties were attributed to changes in microstructure, namely the appearance of grain-boundary austenite after irradiation. This was explained by the occurrence of thermal spikes, that is, microregions which are heated to the austenitic region and quenched to the irradiation temperature, 500–600°C.

Austenitic steels The effects on the tensile properties of austenitic steels are similar to those on ferritic steels, namely, increase in yield and ultimate tensile strengths and reductions in the elongation to fracture and reduction of area values. However, one interesting consequence of irradiating these face centred cubic steels is the appearance of a yield point. This is illustrated in Figure 4 which shows the stress-strain curves for an annealed type 347 austenitic steel before and after irradiation to $7{\cdot}8 \times 10^{19}$ n/cm² (> 1 MeV). The yielding phenomenon is evident in curve C and its dependence on strain rate may be seen by comparing curves B and C.

Neutron irradiation effects at 80°, 300°, and 600°C on the room temperature tensile properties of three grades of austenitic steels are given in Table V. The post-irradiation tensile properties are compared with the properties after holding at the various temperatures for times approximating to the time of irradiation. Lesser changes in properties are produced by irradiation at 300°C than at 80°C and the radiation damage appears to be completely annealed out on irradiating at 600°C. In contrast to ferritic steels, the austenitic grades retain appreciable ductility even after irradiation to 1×10^{20} n/cm² (> 1 MeV) at 80°C. Similar results to these given in Table V for an irradiation temperature of 80°C have been obtained by Wilson and Berggren (*11*).

Bruch and McHugh (*8*) observed that the yield and ultimate tensile stresses of an annealed type 347 stainless steel increased with increasing neutron dose at 80°C. At the maximum exposure of $1{\cdot}2 \times 10^{20}$ n/cm² (> 1 MeV), the yield stress had increased from 49,000–113,000 lb/in². There was an accompanying small decrease in ductility although the material was quite ductile even after $1{\cdot}2 \times 10^{20}$ n/cm². However, in samples of the same steel which had been initially cold worked 7, 17, 37, and 58%, the changes in strength and ductility reached saturation after exposures in the range 0·5 to 1×10^{19} n/cm².

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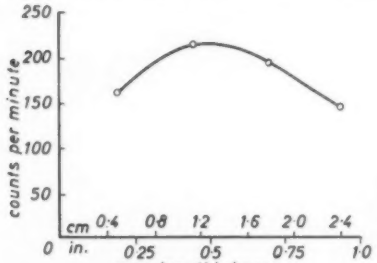
Current interest in the use of beryllium has led to the need for simple assay equipment. The assembly described here is suitable for both field and laboratory use

Instrumentation for beryllium assessment

by H. BISBY, B.Sc., A.M.I.E.E.
Senior Principal Scientist, Electronics Division, UKAEA Harwell

A COMMON DIFFICULTY in any beryllium programme is the need to make a rapid assessment of beryllium content of a sample. Quite recently (*1*), the estimation of beryllium in an air sample has been thoroughly investigated and a spectrographic technique developed which can satisfy sensitivity requirements (2 $\mu g/m^3$ air (*2*) and produce a contemporary result (20 s). This method has also been applied when the beryllium is not in aerosol form. The sample is brought into solution, chemically treated, evaporated to dryness, and then placed in an arc discharge. The process is tedious and slow although an automatic machine recently developed (*3*) will treat and analyse filter paper samples within the range 0·3–50 $\mu g/m^3$ at a rate of six per hour. The machine is somewhat complex and the beryllium must be present in a form capable of being taken up in solution.

None of these techniques is applicable to the assessment of beryllium in mineral samples either because complete chemical extraction of beryllium direct from the sample is not possible, or because the mass of sample which can be dealt with is very small on a geological scale. A technique (*4*) has been shown to be feasible for this special case, and is attractive because it is specific to beryllium, requires little or no sample pretreatment, is non-destructive, and can be applied to bulky samples. The sample is irradiated with gamma radiation and the resultant photoneutron flux (beryllium-9 (γ,n) beryllium-8) is a measure of the beryllium content. A second nuclear method (*5*) measures the neutron flux from the beryllium-9 (α,n) carbon-12 reaction. The method is at best semi-qualitative for most types of samples since the bombarding alpha particle has a range of less than 10 microns in most media.



Concentrate against annular thickness of sample shows optimization of its shape for a given mass (Fig 1)

The alpha-range restriction gives a poor overall neutron yield and the use of very active alpha sources is essential for high sensitivity. The containment of such sources has presented a serious difficulty for this method.

The geological problem

Beryllium is a relatively rare element and of the 40 or so beryllium minerals known, beryl ($Be_3 Al_2 Si_6 O_{18}$) is at present the only commercial source of the element.

BACKGROUND

The demands of nuclear power generating stations operating at high temperatures, such as the AGR, has led to a need for materials able to withstand the high operating temperatures, as well as having the other characteristics associated with reactor fuel elements. Beryllium has properties which are attractive from this point of view. It is light, strong (specific gravity 1·784), has a low neutron capture cross-section and a high melting point (1280°C). Use of beryllium on a large scale raises the problem of obtaining large tonnages of beryllium-bearing minerals and concentrating them to a grade suitable for processing as well as the health safeguards to be maintained when handling both combined and uncombined beryllium.

Containing roughly 10% BeO, beryl normally occurs in pegmatites, in which the overall grade and size vary enormously and the yield is usually small. Most of the commercially available beryl is handpicked or mined on a small scale from weathered zones of pegmatites where the overall grade is of the order of 1% beryl (0·1% BeO). So-called simple field tests rely upon the detection of beryllium chemically or by the determination of specific gravity of small fragments. The chemical test is suitable for only relatively high-grade ore and both methods suffer from inconsistencies arising from sampling procedures.

Although the feasibility of applying the (γ,n) technique to field survey was not originally apparent, earlier work by Gaudin (*4*) proved that the technique offered an indisputable aid in sample assay. With the development of laboratory assay equipment, however, the sensitivity of the

technique, using modern neutron counters, and the use of lightweight, low-voltage transistor circuits made it possible to consider a portable field instrument which would make known procedures for beryl survey obsolete.

The photodisintegration process

The photodisintegration process ((γ,n) reaction) which occurs when beryllium-9 is subjected to gamma-radiation of energy Q_γ can be expressed in the form:

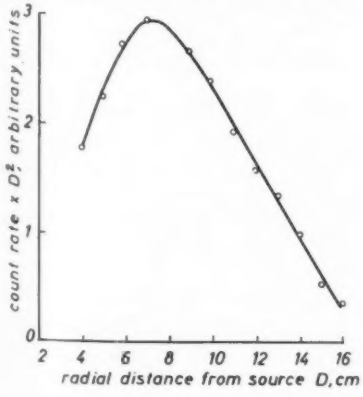
$$Be^9 + Q_\gamma \xrightarrow{Q_t} n + Be^8 \qquad Q_\gamma > Q_t \qquad (1)$$

where Q_t, the threshold energy for the reaction, is 1·63 MeV. Neutrons are liberated from the beryllium-9 nucleus with an energy approximately equal to the excess energy above 1·63 MeV of the bombarding radiation. This threshold value is lower than those for all other elements, which, apart from deuterium (Q_t = 2·23 MeV), are in excess of 5 MeV. Thus if the gamma radiation has an energy range between 1·63 and 2·23 MeV, the neutron flux originated is directly associated with the beryllium-9 content. The nuclear cross-section of the reaction is of the order 10^{-3} barns, so that the number of neutrons originating from a sample will be given by:

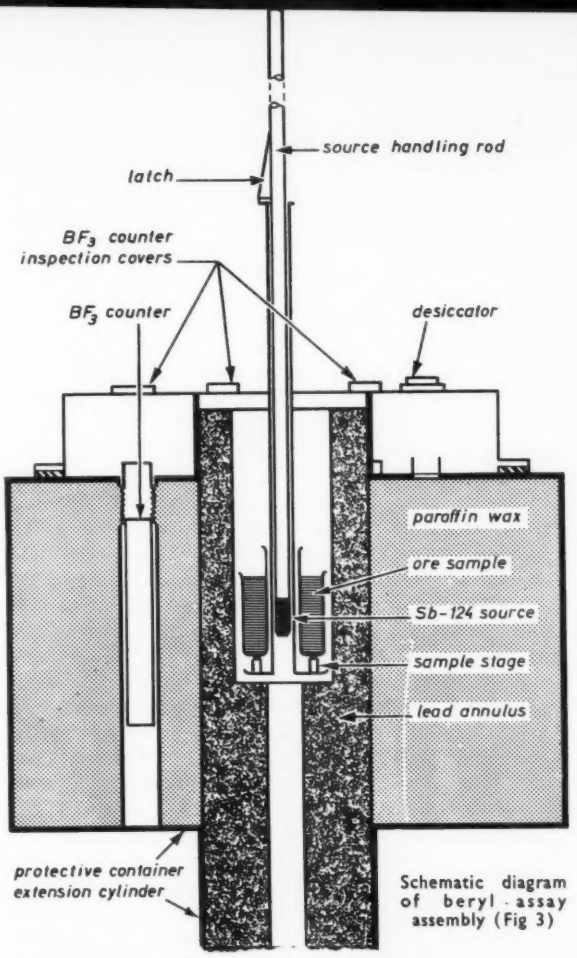
$$N = \frac{MFZ}{A} \times 10^{-27} \text{ n/s} \qquad (2)$$

where M = mass of Be^9 present (g), A = atomic weight Be^9 = 9·02, F = photons per cm^2/s, Z = Avogadro's number = $6{\cdot}02 \times 10^{23}$.

The gamma source used for this work is antimony-124 which has energies ranging from 0·6 to 2·30 MeV, of which 1·692 MeV is predominant at 40–50% of total activity. Neutron irradiation of the stable element (Sb-121 57%, Sb-123 43%) in a reactor produces the radioisotopes Sb-122 (T = 2·8 days) and Sb-124 (T = 60 days). Antimony-122 has a predominant gamma energy of 0·57 MeV (66%) which, although less than Q_t, increases the radiation hazard of the source. The effective gamma radiation, having only 60 KeV excess energy over the threshold limit, is rapidly degraded in the sample itself and the neutron yield per unit thickness of sample shows a marked decrease with increasing sample thickness. The neutrons originating from the reaction have a maximum energy of 60 keV so that the energy spectrum of the neutrons emerging from the ore sample is spread over the range 0–60 keV. The highest detection efficiency is therefore likely to be obtained by surrounding the sample with a moderator thick enough to ensure thermalization of all neutrons, and then to use thermal neutron detectors such as BF_3 proportional or ZnS-B scintillation counters.



There is an optimum distance between the source and the BF_3 counters in the moderator (Fig 2)



Schematic diagram of beryl assay assembly (Fig 3)

Taking into account, therefore, the geometrical disposition of the gamma source and sample γ(fg), the neutron source and detectors n(fg) and the absorption factors for gamma radiation γ(fa) and neutrons n(fa) the number of neutron counts registered can be expressed as:

$$N = \gamma(fgfa).n(fgfafe).msx\ 10^{-6} \text{ counts/s g m c\%BeO} \qquad (3)$$

where n(fe) is the neutron detection efficiency, m = the mass of sample, s = the source strength, x = the percentage grade of BeO. Even for a highly active source, the expression indicates that the design of the instrument for the 'cut-off' grade of 0·01% BeO requires high source/sample, sample/detector geometrical factors, efficient neutron detectors, and a large mass sample.

Beryl assay assembly

The most convenient and efficient method of irradiating large samples uses a cylindrical geometry with the gamma source mounted centrally on the axis of the annular vessel containing the sample. This container is surrounded in turn by a second annulus of hydrogeneous moderator in which the thermal neutron detectors are embedded. Boron trifluoride counters are used for neutron detection since Owen (*6*) has indicated their superiority over scintillation counters when required to operate in a high flux of gamma radiation.

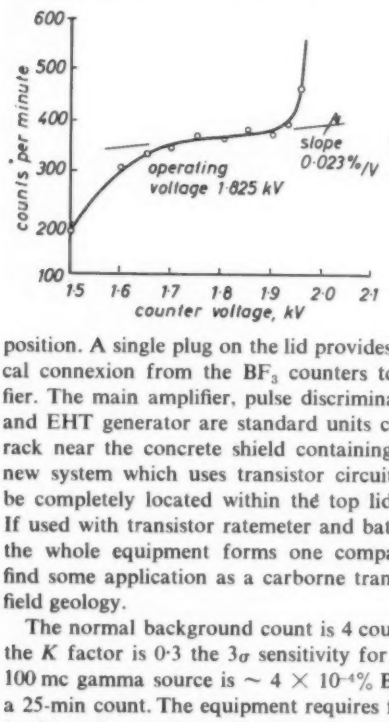
Any one of such physical arrangement can be assigned an 'efficiency factor' (K) expressed in counts/min/mc of gamma source/gram of sample/%BeO.

i.e. $n = Ksmx$ counts/min (4)

Factor K should be as large as possible since the counting time per assay and the gamma-source activity, *mutatis*

mutandis, are inversely proportional to K, a low value for both being highly desirable features. Equation 3 indicates that K is influenced by source geometry, the extent of gamma and neutron absorption in the sample, and by the efficiency of neutron detection. Figure 1 shows that the sample shape can be optimized for a given mass of sample. Figure 2 indicates that there is an optimum position for the BF_3 counters in the moderator (*7*).

Figure 3 is a general schematic diagram of the assay assembly. Paraffin wax is used as moderator and holes are drilled into it for the five BF_3 counters (12EB40) which are mounted from and sealed into the desiccated space provided by the lid of the assembly. When the source is in the assay position, the 1-in. thick lead annulus is sufficient to allow a good BF_3 count-rate/EHT plateau but the dose-rate outside the moderator is above the maximum permissible level for a 40-h working week. For this reason, the assembly is installed in a concrete shield. The integrated dose to an operator is considerably reduced by returning the source to the lower lead annulus ($1\frac{3}{4}$ in.) between assays. The arrangement allows the sample holder to be filled level with crushed beryl (100 g) external to the assembly and then inserted into position before the source is brought into the assay



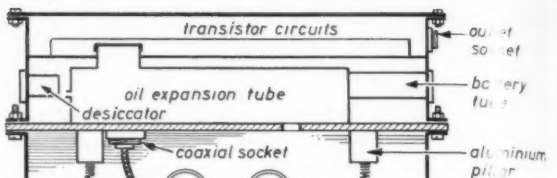
Graph of the plateau of the field survey equipment (Fig 4)

position. A single plug on the lid provides a direct mechanical connexion from the BF_3 counters to the head amplifier. The main amplifier, pulse discriminator, scaler, timer, and EHT generator are standard units contained in a 4-ft rack near the concrete shield containing the assembly. A new system which uses transistor circuits throughout can be completely located within the top lid of the assembly. If used with transistor ratemeter and batteries (1·5 V cells) the whole equipment forms one compact unit and may find some application as a carborne transportable unit for field geology.

The normal background count is 4 counts/min and since the K factor is 0·3 the 3σ sensitivity for 100-g sample and 100 mc gamma source is $\sim 4 \times 10^{-4}$% BeO equivalent for a 25-min count. The equipment requires frequent standardization with samples of known Be content to take into account the 60 day half-life of antimony-124.

Field survey equipment

The survey instrument must necessarily irradiate the rock face with gamma rays and detect the neutrons which emerge. An inverse fourth power geometrical law operates in this case. Thus whilst requiring to irradiate as great an area as possible with as large a source as possible, a compromise is necessary to restrict the gamma flux reaching the neutron detectors and the operators within tolerable limits. Lead screening can be used, but its weight must



Cross-section of field survey equipment (Fig 5)

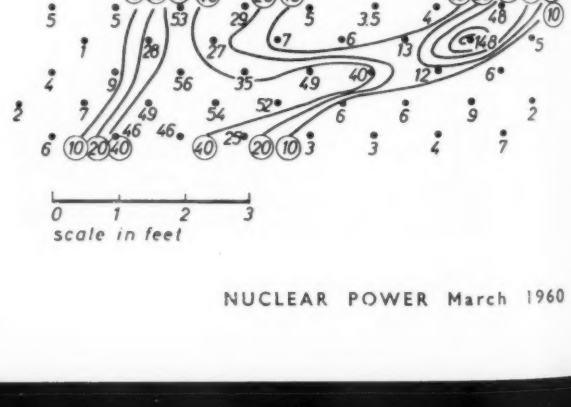
be small enough to allow the instrument to be handled over rough country and placed at inconvenient angles on rock faces, in pits, and mines. A photograph of the 40-lb instrument with its two 4-ft carrying handles is shown on p. 101 of the January 1960 issue of NUCLEAR POWER.

The possible systems afforded by ZnS-B (*8*) and BF_3 counters have been examined and whilst the work was not exhaustive, the general implications were that for equivalent sensitivity the two systems would require equivalent moderator bulk but slightly more lead screening for the ZnS-B system. It was likely, however, that the overall stability of the BF_3 system would be better (Figure 4), so this was pursued. By immersing the BF_3 counters in transformer oil, a wide range of gamma-source/lead-screen/moderator/detector geometries were investigated and a relatively efficient one chosen which, from an engineering point of view, is adaptable to the requirements associated with a field instrument i.e. robustness, resistance to shock, ease of handling, small bulk, and small weight.

A cross-section of the system chosen is shown diagrammatically in Figure 5. The upper compartment of the instrument contains the dry batteries and conventional transistor circuits for EHT power, pulse amplifier, fixed discriminator, and output amplifier to operate a relay once for each pulse passing the discriminator. The relay operates a small counting register contained in the indicator unit. The register, necessary for the low count rates normally experienced, introduces a significant loss of count at high count-rates and the range is therefore extended above 120 counts/min by a ratemeter.

With an instrument of this type it is of interest to have some idea of its 'range of detection' in typical rock formations. This was found empirically by gradually increasing the depth of crushed beryl ore (0·1% BeO) under the survey unit and indicated that the mineral content at

Neutron count-rate contour map of beryl exposure (Fig 6)



depths greater than 3 in. does not appreciably contribute to the count rate.

The slope of the plateau (Fig. 5) indicates that the instrument is very tolerant to slight variations in discriminator level, EHT voltage, and transistor amplifier gain. This expected stability has been substantiated on field trials. The count-rate contour map (Figure 6) was obtained on these trials by placing the instrument at the corners of a grid covering the surface of the beryl zone and recording the count-rate at each station. An empirical relationship has been established (*9*) between the count-rate observed over an infinite volume ($> 12 \times 12 \times 4$ in.) homogeneous grade beryl ore as:

$$n = 17 \times s \times x \text{ counts/min mc \%BeO} \qquad (4)$$

The normal background (no beryl present) of 3 counts/min is therefore doubled on 0·004% BeO when the gamma source strength is 50 mc.

Analytical equipment for medical use

Iredale (*10*) has reported an investigation to determine the minimum amount of beryllium which can be measured using the (γ,n) technique, when the sample has a volume ~2 cc, such as might be encountered with a filter paper through which air has been sampled.

In contrast to the large sample facility of the beryl assay equipment, the 2-cc volume is contained within the annular antimony metal gamma source, but apart from additional shielding and sample handling the geometrical arrangement of BF_3 counters and moderator and electronic equipment is basically similar. Using 6 BF_3 (12EB40) counters the K factor has a value 0·33 counts/min c μg Be, and with a background count of 15 counts/min the 3σ value obtained on a count lasting 30 min is ~4 μg Be, when a 1·5 c gamma source is used. Further development is unlikely to increase the K factor more than a marginal amount. The gamma source strength of 1·5 c is thought to be an optimum value and a possible reduction in background will not increase the overall sensitivity by more than a factor 2. Thus although 2 μg Be is a reasonable limit, the technique does not rival the spectrographic technique (*1*) for a routine $\mu g/m^3$ beryllium-in-air monitor, owing to the sampling and counting time delay. However, an advantage not generally recognized for the (γ,n) technique is that the counting time, for a given accuracy, is inversely proportional to the mass of Be present in the sample, e.g. a 25-μg sample can be estimated to within $\pm$ 10% in 2 min with the present unit.

An equipment based on these principles and combined with a sequential test procedure (*11*) is expected to provide an adequate and rapid analysis of a large number of swab filter paper samples containing between 4–50 μg Be such as might arise in a beryllium incident. Although the instrument does not provide any automatic means of feeding the filter paper samples into the antimony source, the cylindrical geometry of the assembly lends itself to the use of a belt system driving the samples into and out of the ends of the 'cylinder.' A similar system could apply to beryllium compounds in solution contained in a process pipe passing through the antimony-124 source.

Equipment for chemical analysis

Using a modification of the beryl assay assembly, Milner (*12*) has investigated the value of the (γ,n) technique in the analytical field of chemistry, using solid and liquid (25 ml) samples. He concludes that the method should not be applied indiscriminately, because of the interference of some elements with high cross-sections for thermal neutrons. The interferences are small except for elements such as boron, cadmium, samarium, gadolinium, and large concentrations of deuterium can cause a small positive error due to the 2·3 MeV γ (0·2%) Sb-124. The analysis of unknown samples is therefore affected by the presence or absence of neutron moderators and absorbers. Under favourable circumstances the method is extremely rapid and precise compared with the chemical methods available. Similar work on the extent of interference due to other elements in minerals of geological interest has been carried out at the Atomic Energy Division, Geological Survey of Great Britain (*9*).

The use of one assay equipment on a current survey of known beryl pegmatites in Rhodesia has reduced the analytical cost alone of the survey by more than £5000 per month. This is largely due to the fact that the technique requires little sample pre-treatment and can be carried out rapidly by relatively unskilled operators. The introduction of six field survey instruments on the same programme is expected to reduce the overall cost of the survey even further, since sample taking and transport, milling operations and the duration of the survey will be considerably reduced by assessments made in the field. The (γ,n) technique is also of potential value in other aspects of a complete beryllium programme. Investigation into beneficiation of low-grade ore by the DSIR Mineral Dressing Laboratory, Warren Springs is receiving assistance from the rapid and reliable analysis provided by a (γ,n) assay unit. Similar units are in constant use at the DSIR National Chemical Laboratory, Teddington, where beryllium extraction and concentration studies are being made. Although the spectrographic technique will satisfy the beryllium-in-air monitoring problem, a development of the (γ,n) assay technique and a possible extension of the survey instrument may well contribute to the solution of problems associated with deposited beryllium. Direct monitoring of the Be content of process liquors either in beryllium production or in the chemical separation of AGR fuel elements is a possibility with the (γ,n) technique. Finally although the incidence of a burst fuel element in an AGR-type reactor can be detected by fission product monitors, these will not give an indication of the beryllium content in the gas coolant streams. This indication might be possible by subjecting the wire collector of a precipitator to a suitable alpha or gamma flux, after passing the fission product scintillation counters, and observing the neutron radiation.

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Japan's first nuclear power station

The reactor has been designed to stringent building and radiation codes

1. ENGINEERING DESIGN

by P. A. LINDLEY, B.Sc., A.M.I.Mech. E. *and* K. J. MITCHELL
Chief Engineer, Design Department, GEC/Simon-Carves Atomic Energy Group — *Chief Design Engineer,*

THE NUCLEAR power station designed by The General Electric Company Limited of England and Simon-Carves Limited for the Japan Atomic Power Company and to be built at Tokai-Mura, 110 km (70 miles) north-east of Tokyo, follows the same general pattern of British design set by the Calder Hall station. Thus it has a graphite moderator, natural-uranium fuel canned in Magnox, and carbon dioxide coolant. As is to be expected, the design incorporates a great number of detail improvements, but it also includes a number of novel features not previously used for such a station.

Aseismic design features

Perhaps the most interesting feature of the station is that it is designed to resist earthquakes. A cross-section through the reactor building is shown in Figure 1. As compared with the earlier GEC/Simon-Carves design for Hunterston nuclear power station the most noticeable effect of the aseismic design is the change from bottom charging to top charging in order to bring the centre of gravity of the reactor as near to ground level as possible. The use of bottom charging was examined in the early stages of the Japanese design, but the resulting structural problems proved quite impossible to solve and it had to be abandoned. There are, in addition, a number of other important features, although these are perhaps less obvious. For example, the station is designed so that the combination of reactor and steam-raising system is entirely self-contained from the safety point of view. In other words, all connexions with outside buildings and services may be severed without prejudice to reactor safety. Consequently, the main control room and auxiliary services such as carbon dioxide supplies, reserve feed water, feed pumps, diesel alternators, and station batteries, are all sited in the reactor structure. The turbine hall forms another self-contained unit.

From the structural point of view, the reactor raft and everything mounted on it is designed to withstand, without damage, an earthquake several time more severe than the 1923 Kanto earthquake. This entails very heavy reinforcement of the raft and superstructure, together with rather unusual support and holding-down arrangements for the heavy plant. For example, the reactor pressure vessel and the steam-raising units are supported both at the top and at the bottom. The reactor vessel has two skirts; a main skirt at the bottom which supports the weight and is designed to take all the lateral loads arising from the core, and a top skirt which is designed to stabilize the upper part of the vessel in a horizontal direction. Similarly, the steam-raising-unit vessels are horizontally supported at the top.

The ducts present a special problem, since they have to be capable of movement in order to accommodate thermal expansions and cannot, therefore, be solidly tied down. The solution adopted here is the use of viscous dampers of special design. The damper consists essentially of a hydraulic cylinder fitted with a small bypass. It offers little resistance to the slow thermal movements but acts as a rigid support when subjected to the comparatively rapid vibrations of an earthquake.

An unusual problem occurs in the design of the charge machine. This 500-ton mass has to be supported so that if an earthquake occurs at any time during its operating cycle it will cause no damage, even when the machine is connected to a standpipe. The design of the charge-machine bridge for these conditions therefore presents problems which are totally beyond the experience of any crane maker, since in addition to the 500-ton vertical load, loads of 400 tons horizontally in any direction must be accommodated with a strictly limited deflexion.

By far the most difficult design problem from the structural point of view has been that of the reactor core. The original tender design was based generally on the same principles as Calder Hall, in that a restraining structure was placed around the graphite and made in such a way that its coefficient of expansion was the same as that of graphite. The method of

THE PROJECT

This gas-cooled graphite-moderated reactor developing 150 MW will be sited close by the Japan Atomic Energy Research Institute at Tokai-Mura. It has been designed by the GEC/Simon-Carves Atomic Energy Group and will be operated by members of the Japan Atomic Power Company. This Company, formed in 1957, consists of nine power companies, the Governmental Electric Power Development Company and leading industrial concerns. The contract was signed in Tokyo on December 22, 1959, preliminary work by the JAPC on the site has begun and excavation for the reactor begins soon. Concreting of the reactor structure will begin at the end of the year and the station will be on power in 1964.

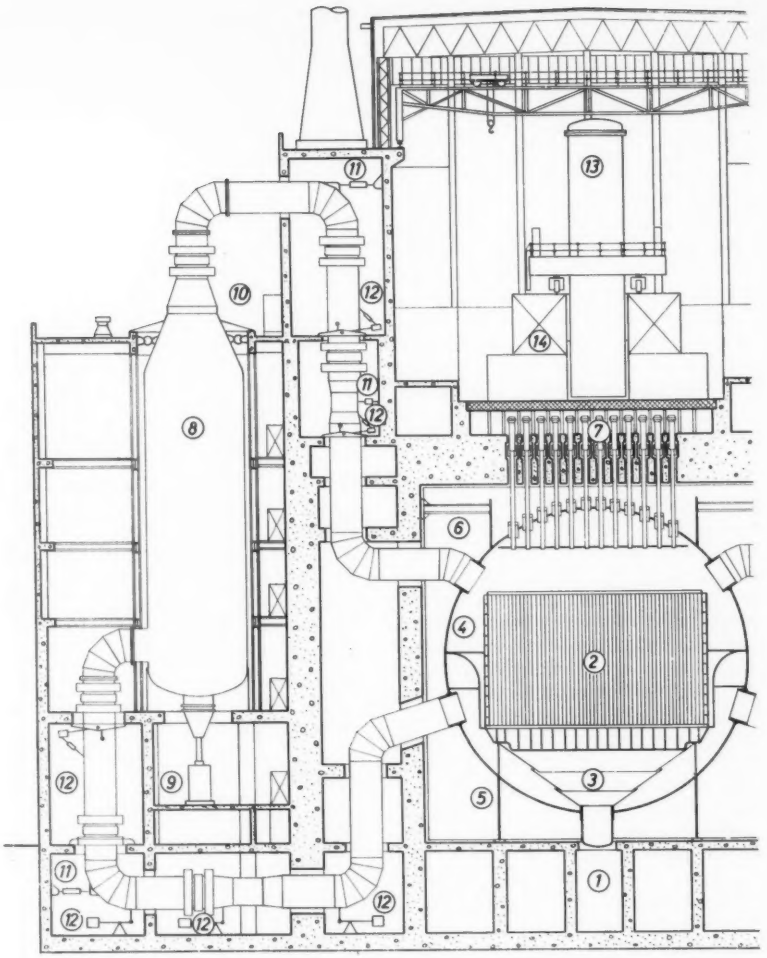


Fig 1 Cross-section of the reactor building, showing general principles of design

1—Reactor raft 2—Reactor core 3—Debris collector cones 4—Pressure vessel 5—Reactor support skirt 6—Pressure-vessel earthquake restraint 7—Charge/discharge standpipes 8—Steam-raising unit 9—Gas-circulator turbine drive 10—S.R.U. earthquake restraint 11—Duct earthquake restraints 12—Duct counterweight supports 13—Charge machine 14—Charge-machine bridge

achieving this, however, was novel and involved a series of stainless-steel members with mild-steel diagonals as shown in Figure 2a. This construction enabled shear forces to be transmitted downwards towards the grid, and thence to the supporting skirt, and enabled the known growth effects to be accommodated.

More recently, however, it became apparent that at the operating conditions of the core shrinkage would later occur, leaving a region of loose bricks in the centre of the core even if the outside were maintained tight. The consequences of having looseness in the core in an earthquake-prone region could not be contemplated, and consequently intensive further work became necessary. The result was a brick and key system which is described more fully by Dr Hicks in the subsequent article. Resulting from the new core design, the core restraint structure has been greatly simplified, being now virtually a plain steel cylinder (Figure 2), and the core has an effective coefficient of expansion equal to that of steel, thus eliminating the need for ball-bearing supports between the core and the grid. An interesting result of the change is the necessity to use a triangular lattice pitch for the first time in the history of this type of reactor.

Disruption of the graphite core could cause a condition where the normal control rods failed to enter in the event of a trip. Secondary shutdown devices are therefore also provided utilizing boron-steel balls that will be able to enter the core under any conditions. The effects of possible duct rupture and loss of gas from the primary circuit have been examined in great detail, and appropriate features incorporated to minimize them.

Because of the lack of experience of aseismic design in the UK it has been necessary to keep in close touch with the Japanese authorities. A team of Japanese experts, led by Professor K. Muto, has given a great deal of valuable help.

Fuel elements

For the Tokai-Mura design it has been decided to adopt a hollow fuel element, canned on the outside only (Figure 4). This gives a significant increase in mean specific rating of the fuel, since the heat-conduction path within the fuel element is shortened and the ratio of primary heat-transfer surface to volume is increased. For the same temperatures the channel rating can be raised very considerably, and although the lattice pitch is increased at the same time the total volume of the core is reduced, with consequent capital savings. Equally important, however, are the savings in fuel investment, which arise mainly from the reduced amount of fuel,

owing to the increased rating.

Several new design problems have had to be overcome. Firstly, there is no suitable solid material which can be placed in the central hole without sacrificing some of the advantages of the design. Consequently, the space has to be left empty and the fuel element must be designed to resist the external pressure and possible inward leakage of the coolant gas. The former is primarily a creep problem but the latter involves several subsidiary questions. For example, in the event of a can failure, inward leakage might impede the outward flow of fission products and therefore the detection of the burst fuel element. If the coolant gas gained access to the hollow space, the high temperature at that point would be expected to cause very rapid oxidation of the uranium. Again, if gas leaked into the central space and the reactor was subsequently depressurized, the gas trapped in the hollow space might force the end caps off the fuel element. These problems have been solved by welding zirconium end-plugs into the uranium bar, so that it presents the same appearance as a solid rod as far as the coolant gas is concerned. A considerable effort has been put into the development of a successful zirconium-to-uranium weld.

Apart from the hollow feature, the fuel-element design is very similar to that adopted at Hunterston. The can is longitudinally finned with helical swirlers and is supported by a zirconium beam inside a graphite sleeve. The main difference lies in the grappling arrangements provided at the top for charge and discharge purposes.

Fuel handling

The fuel-handling scheme presents some novel problems which arise both from earthquake considerations and from the large transport distance involved, since it is envisaged that initially fuel will be supplied from and returned to the UK.

The fuel elements are delivered as sub-assemblies into a store on the site which will hold 15% of a complete reactor charge. This represents 90 days of operation at full power. The sub-assemblies are kept in their transport containers until required for charging, when they are transferred to the fuel-handling building in the reactor structure. Here they are unpacked and assembled under clean conditions into complete fuel elements, and then passed via storage racks to a loading point where they are loaded into magazine tubes, ready for insertion into the charge machine.

The charge machine is mounted on a travelling bridge from which it can serve any of the 168 standpipes and also visit the fuel loading and unloading points in the fuel-handling building. Further stations are provided for machine maintenance and the collecting and depositing of control assemblies. A standby machine is also installed. A sketch of the proposed dimensions of the charge machine and bridge is given in Fig. 3.

In a normal operating cycle, the charge machine collects a fresh control assembly and is then loaded with magazine tubes of new fuel. From this point onwards, the sequence of operations is controlled by a preselective punched-card system, which also ensures that the correct standpipe and channel is selected. The machine is sealed on to the appropriate standpipe and raised to reactor pressure, when the standpipe closure is released and raised into the machine together with the control assembly. A charge chute is then lowered into the standpipe to engage with the desired channel, and the fuel elements are removed and new fuel inserted by a grab. During this process, a special cooling system in the charge machine maintains adequate cooling of the fuel elements without allowing the mass flow to rise to the 'levitation' point, that is, the value sufficient to raise any particular fuel element from its position in the core. The same system preheats the new fuel before charging.

After changing the fuel elements, the machine replaces the new control assembly and standpipe closure, and is then depressurized and removed to the fuel unloading point. Here the magazine tubes containing the spent fuel are lowered into the separating room. The charge machine then deposits the used control assembly at a storage point, where it undergoes planned maintenance before being made ready for re-use in the reactor.

In the separating room, the canned uranium cartridge is removed from the graphite sleeve by a remotely controlled machine, and sent down a chute into the cartridge cooling pond. The graphite sleeve is crushed and sent down another chute into a storage bunker in the basement of the building. In an emergency the separating room can be bypassed, and complete fuel elements sent down a further chute to the cooling pond. Facilities are also provided for canning complete fuel elements in an aluminium container, to facilitate the examination of faulty cartridges.

In the cooling pond, a machine removes the swirlers either before or after the decay period, as may be convenient. The cartridges are placed in skips and stored for a normal period of 100 days. Owing to the possible uncertainties of transport over so large a distance, the pond is sized to take a complete reactor charge of fuel plus the quantity delayed in normal throughput.

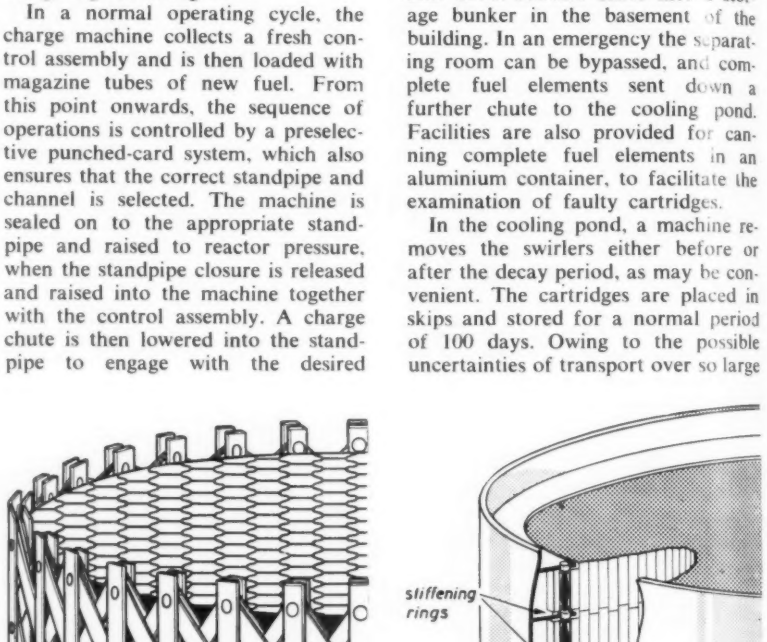


Fig 2 The left-hand figure shows the original design of the core restraint which has the same coefficient of thermal expansion as graphite. The right-hand figure shows the new design of the restraint

Steam cycle and gas-circulator drive

The use of hollow fuel elements and high specific ratings implies a large mass flow rate of gas in the primary circuit, and this in turn demands a high circulator power. To meet this need a new form of gas circulator drive has been developed which is particularly suited to providing a high circulator power at high efficiencies.

In this scheme the gas circulators are similar to those at Hunterston in that they are single-stage centrifugal

machines mounted vertically in the base of each of the four steam-raising units. Instead of being driven by d.c. motors, however, they are driven by back-pressure steam turbines through reduction gears. These steam turbines work between the two pressures of the dual-pressure steam cycle, and the exhaust steam is mixed with the l.p. generated steam before the l.p. superheater, so that a measure of reheat is obtained.

The essence of the scheme is that practically all the h.p. steam is used in the circulator turbines, only a small trickle being led to the main turbines for control purposes. In this way maximum advantage is taken of reheat, and it is found that with the pressures normally obtained in the dual-pressure steam cycle the resulting blower power conveniently matches that required by reactors working at these ratings.

Since the back-pressure turbines are geared units, running at 7700 rev/min and developing 7400 hp each, their proportions are such that a very good efficiency is obtained—approximately equal to that which would be obtained in the h.p. section of the main turbine.

In addition to the obvious capital savings due to the elimination of electric motors for driving the blowers, and their associated switchgear, cabling, and transformers, together with the reduction in size of the main turbogenerators, there is a further capital saving made possible by the use of reheat. This is due to the reduction of the exhaust wetness of the main turbines, which makes possible the use of much larger exhaust stages than has hitherto been considered practicable for nuclear stations.

In addition to economic advantages, this method of blower drive has several important advantages from the point of view of safety. Each of the four gas circulators is arranged as a unit with its own steam-raising unit. It therefore has its own separate power supply quite independent of the other gas circulators, since it is possible to arrange the steam pipework and valves so that failure of any one circulator will not affect the others. Nor will the failure of any one steam pipe affect more than one circulator. This situation is in marked contrast to electric drives, where it is not economically possible to provide more than two alternative supplies to all the circulators.

In addition, in the event of an accident the steam in the h.p. drum presents a large amount of stored energy available for the gas circulator—far in excess of anything which could be provided by means of a flywheel. In any event it is difficult to envisage how the supply could be lost apart from mechanical failures, since under most reactor fault conditions heat is still produced by the reactor and conveyed to the steam-raising units. Hence, the steam would still be available to drive the circulators.

Turbine hall

The arrangement of the turbine hall follows conventional lines. There are two turbogenerators each rated at 85 MW c.m.r., cooled with hydrogen at a pressure of 2·11 kg/cm² (30 lb/in²g). The turbines are essentially single-pressure machines with a small h.p. section to absorb excess steam not required by the gas-circulator turbine.

Radiation shielding

Standards of permissible exposure to radiation, external and internal to the body, have been recommended by the International Commission on Radiological Protection. The British code of practice, based on these recommendations, includes additional safety factors and the radiation design criteria specified for the Japanese station are in several respects even more stringent.

These criteria may be summarized briefly as follows:

a. The maximum annual integrated radiation dose must not exceed 1·5 rem (2·5 rem for British stations and 5 rem the I.C.R.P. figure).

b. Dose rates, even of a transitory nature, above 50 mrem/h, must be avoided for routine operations, and maximum dose rates in areas requiring periodic entry must not exceed 2 mrem/h.

c. The radiation level where persons unconnected with the reactor normally have access must be less than 0·5 mrem/h.

d. The maximum permissible dose rate to non-occupational personnel must not exceed 1/10 of the occupational maximum permissible level.

The dose rates referred to include all possible sources arising from the station, that is, external exposure due to gamma rays and neutrons and doses arising from any radioactive effluents. These stringent conditions applied to the design also ensure that restrictions on the operation and maintenance of the station are reduced to a minimum.

Core shielding is effected by the steel of the spherical pressure vessel and 3·1 m (10 ft) of concrete of density 2·32 g/cm³. Axially there is additionally a boron-steel thermal-neutron shield and a 600-mm (2-ft) thick secondary dense concrete shield above the control-rod-standpipe heads. Impurity activation in the coolant, (principally argon-41 and nitrogen-16) makes it necessary to shield the steam-raising units with concrete walls, 600-mm (2-ft) thick up to about 14 m (46 ft) from the ground and 250-mm (10-in.) thick to the level of the hot ducts. Calculations of site radiation levels indicate that the maximum dose rate at ground level will not exceed 0·5 mrem/h. At all times, from discharge from the reactor until final removal from site the irradiated fuel is carefully shielded.

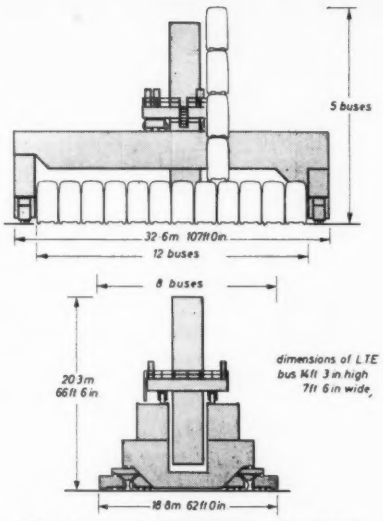


Fig 3 Proposed dimensions of the charge machine and bridge

Adequate effluent treatment plant, and an 80-m (265-ft) high stack fitted with filters, for discharge of the shield coolant air and any carbon dioxide leakage from the coolant circuit, ensure that permissible radiation levels are not exceeded anywhere around the station. Installed and portable monitoring equipment is provided, and located at appropriate places within the buildings and boundary to monitor the radiation level, the concentration of radioactive gases, and carbon dioxide, thus enabling proper action to be taken at all times to ensure the safety of the site and surrounding areas.

Fig 4 Cut-away model of the fuel element

東海村

Japan's first nuclear power station

Special precautions are taken in the structure of reactor core, pressure vessel, and gas ducts

2. EARTHQUAKE PROBLEMS

by R. HICKS, M.Sc., Ph.D., A.M.I.C.E.
Head of Structural Development Section, GEC/Simon-Carves Atomic Energy Group

A FUNDAMENTAL problem in designing any structure against earthquakes is that the additional loads imposed during an earthquake cannot be predicted accurately. Furthermore, the dynamic behaviour of any particular structure depends on a number of intractable factors, such as the inherent degree of damping and the foundation conditions. Thus the formulation of design criteria for an earthquake-resistant structure is particularly difficult, and must be determined from structural designs that have proved to be safe during past earthquakes.

Earthquake design loads

For some structures, including most of those associated with a nuclear power station, an earthquake can be considered from a design point of view as resulting in additional forces acting vertically and horizontally through the centre of gravity of each component, and proportional to its mass. Thus, if W is the weight of a structural component, the temporary horizontal and vertical earthquake loadings would be $C_H W$ and $C_V W$.

The seismic coefficients C_H and C_V are given in some instances by the building codes of the countries concerned. They vary from code to code, and may depend also on the particular geographical region, the foundation conditions, and the type of structure under consideration. The Japanese Code, given in the Building Law Enforcement Order, 1950, gives C_H as 0·2 for a building section less than 16 m (52 ft 6 in.) above the ground, with an additional 0·01 for every 4 m (13 ft) above this. The values may be reduced by a half in consideration of the past earthquake records in the district concerned, and the nature of the construction and foundation. With regard to the vertical coefficient C_V, it is interesting that this can be neglected in some cases, since many conventional structures have sufficient inherent strength to withstand additional dead loads far in excess of those normally imposed by an earthquake.

In adapting the Japanese Code to the design of the nuclear power station, a policy of extreme safety was adopted and the specified horizontal seismic forces were increased by the following factors:

1. for the reactor building and its foundation mat (except those parts in 2 and 3 below)—1½;
2. for the biological-shielding structure, steam-raising units, and their principal sub-structures—3;
3. for all structures and structural parts inside the biological-shielding structure and steam-raising units—3, with simultaneous vertical forces equal to half the horizontal ones.

For the gas ducts, joints, and supports, a seismic coefficient of 2·0 in all horizontal directions was specified. The height datum was also taken as the underside of the raft instead of as ground level.

By comparison, scientific records and historical letters indicate that the largest earthquake in the Tokai-Mura area over the last ten centuries had an intensity no greater than 0·23 g on the surface of the ground. At the level of the raft supporting the reactor building, the accelerations would be even less, and it is reasonable to conclude, therefore, that the earthquake forces the station will have to resist will be considerably less than those for which it has been designed.

Reactor core

The reactor core consists of a cylindrical stack of graphite bricks supported on a plate-girder grillage and contained within a cylindrical steel shell designed to give additional stability to the graphite structure during an earthquake. Except at the boundary of the core, each brick in the moderator and reflector is a hexagonal prism approximately 230 mm (9 in.) across the flats and 940 mm (37 in.) long. There are no tiles. As shown in Fig. 1, keys and keyways are machined on alternate sides of the bricks. Thus, when the core is assembled, there is a complete interlocking of the graphite bricks in a layer since the key of one brick will be located in the keyway of an adjacent brick. Interlocking of adjacent layers is achieved by staggering alternate bricks between the layers.

The bricks in the central region forming the moderator are centrally bored, thus forming a core with a triangular lattice. To maintain a complete interlocking of the bricks without reducing locally the structural strength of the core, control rods are located in empty charge channels rather than in specially prepared channels at the intersection of three bricks.

Fig 1 Typical graphite moderator brick

Body forces due to an earthquake can be transmitted readily from brick to brick via the keys and hence through the stabilizing cylinder into the grillage and bottom skirt. Furthermore, the geometry of the bricks enables the core to expand symmetrically in a radial direction without imposing any type of restraint on the keys. For example, during start-up of the reactor,

the thermal expansions of the stabilizing cylinder and grillage are about three times as large as for the core. Thus every brick is dragged out a small distance radially, forming a gap of approximately 0·58 mm (0·023 in.) between the faces of adjacent bricks and resulting in an overall expansion of the core equal to the thermal expansion of steel. Actually, the core will be constructed with small initial gaps between adjacent brick faces (Fig. 2), these gaps becoming larger during operating conditions.

Another feature of the interlocked core is that each individual brick can expand or contract relative to its own centre without experiencing restraint from adjacent parts of the core. After prolonged irradiation every brick tends to shrink; but since the irradiation damage across a key and keyway is the same, there is no change in the initial clearance in the keyway. At the same time the radial keys ensure that the bricks shrink towards their own centres, thus opening gaps between adjacent brick faces. In practice, even in the most highly irradiated part of the core, this gap will be only about 2·5 mm (0·1 in.) after twenty years.

In general, it may be observed that whilst the radial keys permit temperature and shrinkage movements of bricks without restraint, they resist non-symmetrical distortion of the core as a whole, except in so far as there is a very limited amount of distortion due to clearances between keys and keyways. At the same time it is impossible to jam a key in a keyway either by displacement or rotation of a single brick.

Calculations show that provided the load is transmitted smoothly there is a large factor of safety on the structural strength of the core even when the horizontal earthquake load is taken as high as 0·7 *g*. Two factors ensure a smooth distribution of boundary reactions of the core. Firstly, the steel stabilizing cylinder and core are connected by relatively flexible spigots which prevent load concentrations. Secondly, the core consists of thousands of unit bricks which during an earthquake tend to distribute the load more smoothly than in the case of a core made up of a small number of large monolithic units, each with a correspondingly large number of keys and keyways.

Reactor pressure vessel and supports

The reactor pressure vessel is a sphere of fine-grain aluminium-killed steel having a diameter of 18·9 m (62 ft) and a thickness of 83 mm (3¼ in.); its gross weight is about 1500 tonnes, and it has been designed to withstand an internal pressure of 16·2 kg/cm² (230 lb/in²). The vessel is supported by a cylindrical skirt having a diameter of 12·4 m (40 ft 9 in.) and a thickness of 63·5 mm (2½ in.). During normal operating conditions this skirt supports the combined weight of the pressure vessel, reactor core, grillage, etc. (approximately 4000 tonnes), while in the event of an earthquake it resists vertical oscillations corresponding to an additional dead load of approximately 1300 tonnes.

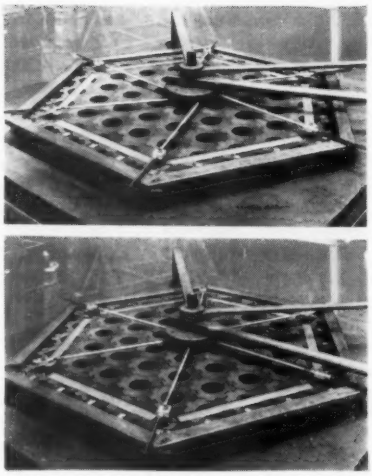
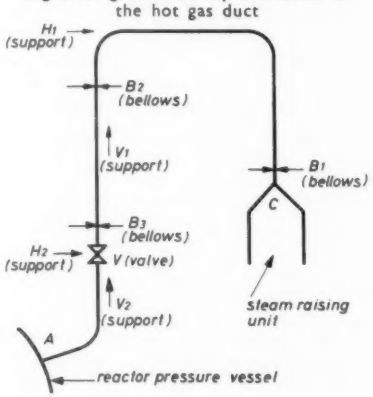


Fig 2 This model of part of the moderator shows initial (top) and operating (bottom) clearances

The skirt is extended several feet into the vessel to form a support for the plate-girder grillage which carries the reactor core. The actual length of the internal skirt was chosen to be as short as possible, consistent with the condition that its length was sufficient to permit substantial attenuation of applied edge bending and shear stresses.

In addition, there is another skirt located on the outside of the vessel above the equator. This skirt is 2·54 mm (1 in.) thick, and has been designed to transmit a portion of the horizontal earthquake load from the reactor pressure vessel to the biological shield. This is effected by two thin steel diaphragms located in horizontal planes at the upper end of the skirt and anchored to the inner face of the biological shield. The diaphragms have sufficient flexibility to allow vertical temperature movements of the top skirt without imposing serious restraining forces on the vessel.

Fig 3 Diagrammatic representation of the hot gas duct



For the design of the JAPC reactor pressure vessel, a detailed stress analysis showed that by suitably choosing the thickness of the various skirts the bending stresses induced in the structure could be kept relatively low, so that the sum of the membrane and bending stresses in the vessel and skirts at the point of discontinuity was everywhere considerably below the yield stress of the material even during a severe earthquake.

Basically the analysis of the skirt problem reduces to the finding of the unknown bending moments and shear forces induced in the four components of the structure meeting at the discontinuity. The general analysis previously developed (*1*) was applicable to the case of normal operating stresses in the Japanese reactor vessel.

For the earthquake stresses, which are non-symmetrical, additional analysis was necessary. This was done by Leckie and Livesley (unpublished) of Cambridge University, using equations developed by Flügge (*2*) for the sphere and by Hoff (*3*) for the skirts. It was found that during an earthquake the horizontal shear on the reactor core is carried mainly by the bottom skirt, while the horizontal shear on the pressure-vessel standpipes is transmitted almost completely to the biological shield via the top-skirt diaphragms. On the other hand, the horizontal earthquake body forces on the sphere are shared more or less equally between the top and bottom skirts.

It is interesting that if no top skirt is used, the induced earthquake stresses at the bottom skirt-to-shell junction are increased by a factor of about three, and that this increase can be mainly attributed to the additional overturning moment on the bottom skirt by the standpipes located at the top of the reactor pressure vessel.

The full analysis for the stresses at the junction of the vessel and support skirt involves a great deal of numerical computation; for example, sets of more than thirty simultaneous equations have to be solved to determine the magnitude of the earthquake stresses alone. For this reason, where possible, experimental work has been done to verify theoretical calculations, and to justify the use of particular shell theories. Thus a one-sixth scale

model of the sphere and support is being used in the GEC laboratories to check earthquake stresses, while a full-size mock-up of part of the support skirt is used to determine temperature gradients for the evaluation of thermal stresses. Furthermore, additional experimental work is being done independently in Japan under the direction of JAPC.

Main gas ducts

Consideration of such features as mass flow, frictional losses, and the number of steam-raising units, led to a final duct diameter of approximately 1·8 m (6 ft). To ensure sufficient flexibility for temperature expansions, three hinged bellows are incorporated in each duct system, the bellows being designed to take an axial load without transmitting any appreciable bending moment.

The system must be such as to ensure that there will be no danger of resonance with earthquake vibrations. Since each duct system is co-planar, deflexions in normal directions have been restricted by introducing a series of sliding supports which merely permit axial and diametral thermal expansions, while vertical and horizontal earthquake deflexions in the plane of the system are restricted by a number of viscous dampers. Lobster-back bends are used in the ductwork to increase overall flexibility. The hot-duct system is shown diagrammatically in Figure 3. The total mass of the bellows and valves is of the same order as the mass of the complete duct system from A to C.

An initial calculation showed that in the event of an earthquake the duct system became seriously over-stressed unless supported at a number of intermediate points along its length; furthermore, mainly because of the pressure of the bellows, gross displacements were likely to occur owing to forced vibrations. For this reason additional horizontal supports were placed at the points H_1 and H_2, and additional vertical supports were placed at V_1 and V_2, these latter supports being designed so as not to carry any of the dead load of the ducts during normal operating conditions. Since considerable movements occur in the ductwork because of temperature changes in the reactor during normal operating conditions, and because these movements are relatively slow compared with the frequency of vibration of an earthquake, the additional support for the ductwork is supplied by using viscous dampers at the intermediate points mentioned above. In an earthquake the deflexions of these supports will depend on the periodicity of the applied loading, the natural frequency of the ductwork, and the viscosity of the dampers themselves.

In practice it is necessary to consider the simultaneous deflexions of all the damper supports during an earthquake, and to adjust the viscosity of the various dampers to prevent excessive stresses in any part of the system. Furthermore, since the deflexions of the restrained duct system are inherently small, the additional flexibility due to the lobster-back bends and the localized flexibility of the reactor pressure vessel at the point A have to be taken into account.

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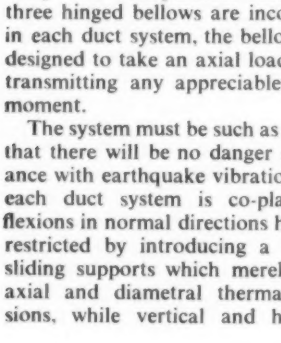


Japan's first nuclear power station

Novel fuel element and circulator drive features are incorporated

3. OPTIMIZATION

by R. H. BIRD, B.Sc.Tech.(Hons.)

Chief Performance Engineer, GEC/Simon-Carves Atomic Energy Group

THE TOKAI-MURA design represents the second round of development of natural-uranium gas-cooled reactors for power production, the Hunterston station being representative of the first round. Table I gives a comparison between the design performances of the two stations, which have roughly the same nominal output, and draws attention to some of the improvements that have resulted from three years' development. The anticipated performance of the Hunterston reactor has been corrected to that which would be obtained if it operated with the same circulating-water temperature as at Tokai-Mura, that is 20°C (68°F) instead of 13°C (55°F).

It will be seen that the physical size and uranium investment have been considerably reduced in the later design, that is, the plant and uranium ratings have been increased. This has resulted in a considerable increase in circulator power consumption but in spite of this the thermal efficiency of the station has been increased.

There are many reasons for the advance represented by the Tokai-Mura design. There are, however, two fundamental differences which affect the economy of the whole plant;

1. the hollow fuel element; and
2. the turbine drive adopted for the gas circulators, coupled with the use of a reheat steam cycle.

Both these improvements have arisen from the desire to increase fuel and plant ratings to reduce capital costs. However, the guiding principle in selecting the design conditions has been to achieve the lowest cost per unit of sent-out power, which means in practice accepting the best compromise between improvements resulting in lower capital costs and those resulting in higher efficiencies and lower running costs.

Hollow fuel elements

The quantity of heat that can be removed from a given quantity of uranium in this type of reactor is limited by the permissible maximum

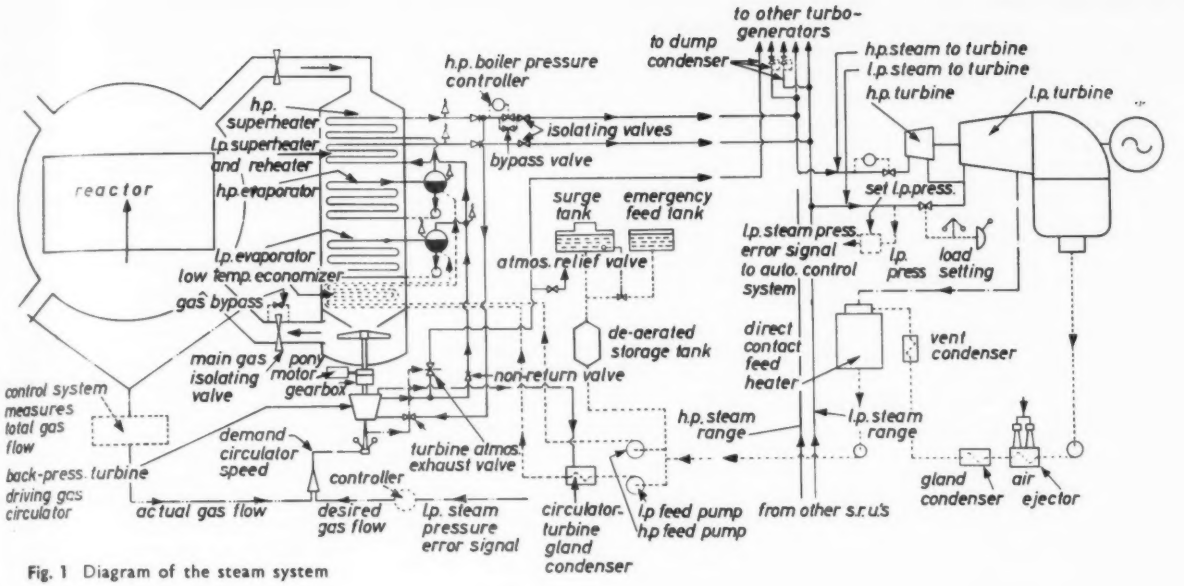


Fig. 1 Diagram of the steam system

temperatures of the Magnox can and of the uranium fuel. Detail development has concentrated on improving the can cooling surface so that for a given can temperature more heat can be removed without an excessive gas pressure drop. There are manufacturing and physical limits to what can be achieved and a more fundamental approach is to increase the surface-area/volume ratio of the uranium itself. This can be done by using rods of small diameter, but these introduce problems in fuel-element support and in reactor design. More important than this, simply reducing the rod diameter does not overcome the limitation imposed by the maximum uranium temperature. A simple analysis of the heat conduction in a uranium rod of diameter d and conductivity k shows that the maximum uranium temperature at a position in the reactor where the heat production per unit volume is h is given by:

$$\theta_{u,\max} - \theta_o = hd^2/16k,$$

where θ_o is the rod surface temperature, which can be assumed equal to the can temperature if the rod/can interface resistance is ignored. The fuel is arranged in a number of channels and if the heat output per unit length of channel H_l is substituted in the above formula the following expression is obtained:

$$\theta_{u,\max} - \theta_o = H_l/4\pi k.$$

For fixed temperatures the heat output per unit length of channel is fixed whatever the rod diameter, and hence the use of small-diameter rods leads to a large number of channels.

TABLE I

Comparison of Hunterston and Tokai-Mura Reactors Operating at Fuel-Cycle Equilibrium with a Circulating-Water Inlet Temperature of 20°C (68°F)

	Hunterston	Tokai-Mura
Nominal max. can temp., °C (°F)	454 (850)	454 (850)
Reactor heat output, MW	569	570
Circulator power consumption, MW	13	22
Net power output, MW	154	158
Net station efficiency, %	27·0	27·7
Weight of uranium, tonnes	251	172
Number of fuel channels	3288	1916
Mean specific fuel rating, MW/tonne	2·26	3·31
Heat output per unit length of channel at most highly rated point in reactor, W/cm (kW/ft)	488 (14·9)	1000 (30·6)
Reactor vessel internal dia., mm (ft)	21,350 (70)	18,900 (62)
Reactor vessel thickness, mm (in.)	73 ($2\frac{7}{8}$)	83 ($3\frac{1}{4}$)
Operating gas pressure, kg/cm² (lb/in² g)	10·6 (150)	14·4 (205)
Number of steam-raising units	8	4
Steam-raising-unit internal dia., mm (ft)	5945 (19·5)	6260 (20·5)

The data quoted represent improvements in the design originally tendered, and final details remain to be agreed with JAPC.

These must be pitched very closely together to accommodate them in a core of reasonable size; or else the fuel elements must be arranged in clusters of rods, which introduces many design difficulties.

The use of hollow elements overcomes the above difficulties. The surface/volume ratio is high, for a given quantity of uranium, and therefore the heat can be removed adequately from the surface even though the can temperature is limited.

The maximum uranium temperature in a hollow rod of external and internal diameters d_o and d_i respectively, with no heat removal from the inside, is given by:

$$\theta_{u,\max} - \theta_o = \frac{H_l}{4\pi k}\left[1 - \frac{2\ln(d_o/d_i)}{(d_o/d_i)^2 - 1}\right].$$

For equal temperatures in hollow and solid rods the outputs per unit length are in the ratio of:

$$\frac{H_l\ (\text{hollow})}{H_l\ (\text{solid})} = \frac{1}{\left[1 - \dfrac{2\ln(d_o/d_i)}{(d_o/d_i)^2 - 1}\right]}.$$

For the dimensions chosen, this ratio is 2·25 : 1. Hence the output per channel can be high in spite of the uranium temperature limitation, and a high reactor rating can be obtained.

The choice of reactor core dimensions was made after optimization studies similar to those reported for gas-cooled reactors with solid rods, the object being to determine the dimensions which would give the required

power output from the smallest core, with the temperature limitations considered above and with the reactor vessel thickness limited to 83 mm (3¼ in.). The only difference between these and other studies was that in this design there is an additional variable among the dimensions, namely the bore of the hollow element. These studies took into account the heat-transfer and reactor-physics properties of various arrangements and their effects on the power-plant efficiency and from them the fuel-element dimensions mentioned above were selected.

The weight of uranium is similar to that in a solid rod of 33·3-mm (1·31-in.) diameter, appreciably larger than the diameter of about 29 mm (1⅛ in.) common in solid-rod reactors. As might be expected, to maintain a balance between the loss of neutrons in uranium-238 and in the moderator and other core components, the optimum lattice pitch was also found to be higher than in solid-rod designs. The lattice selected—equilateral triangles of 23·6-mm (9·3-in.) side—is equivalent to a 22·9-mm (9-in.) square lattice in which the control rods do not occupy positions in the lattice.

This large pitch is a secondary result of choosing a hollow fuel element but it has a considerable effect in easing many of the reactor design problems. Many dimensions, for example the pitch of the charge tubes, are increased to correspond, and the crowding of the charge face is greatly reduced.

The heat output obtained from a channel of fuel elements is limited by the temperatures discussed above and by the so-called 'levitation' of the fuel element during operation. To remove the heat from a highly rated channel a large gas flow is required, resulting in a high pressure drop over the channel length. This pressure drop acts on the fuel element, tending to lift it out of the core.

The lifting force can be reduced either by increasing the diameter of the channel (thus reducing the gas velocity) or by reducing the gas temperature at inlet to the channel (thus reducing the gas flow required for heat removal). Both methods involve economic sacrifices in the design. The first increases the neutron streaming losses up the channel and reduces the heat-transfer performance of the fuel element, hence spoiling the reactor neutron economy and reducing the thermal efficiency of the station; the second reduces the thermal efficiency. Channel diameters and temperatures over suitable ranges were considered; the combination adopted is one that accepts a high pressure drop (up to the safe limit permitted by levitation considerations) and therefore accepts a high circulator power, but without sacrificing, thermal efficiency. This is achieved by the adoption of the back-pressure turbine drive for the gas circulators.

Circulator drive

The problem of choosing a suitable method of drive for gas circulators that may be required to develop up to 10,000 hp is one of the most interesting in reactor engineering. The complexity of the problem is probably well demonstrated by the fact that in the six designs of gas-cooled power reactors now under construction or operating in the UK there are five different methods of circulator drive. That for Tokai-Mura makes a sixth. It may be noted that the variable-speed d.c. motor drive adopted at Hunterston was not suitable for the high circulator power required in the Tokai-Mura design.

The Tokai-Mura circulators are driven through reduction gearing by back-pressure turbines which take steam from the high-pressure system of the steam-raising units and exhaust it to the low-pressure system where it is reheated before passing to the main power-generating turbines (see Fig. 1).

As at Hunterston, the circulators are centrifugal, vertical-shaft machines, each contained in the base of the pressure shell of one steam-raising unit. The steam-raising units are of the conventional type with finned-tube elements in cross-flow, designed for a dual-pressure steam cycle but with the low-pressure superheater capable of handling the combined flow of live low-pressure steam and the circulator-turbine exhaust steam, thus serving the combined purpose of superheater and reheater. The circulator turbine is a five-stage impulse turbine connected to the circulator shaft through a speed-reducing gearbox. This gives the turbine designer great freedom in the choice of turbine speed and results in a high-speed turbine of extremely small dimensions—the turbine casing is approximately 900-mm diameter by 1000-mm long (3 ft by 3 ft 6 in.)—which has an efficiency equal to that of the high-pressure cylinder of a large modern turbogenerator. Control is by means of throttle-governing, varying the speed of the turbine and circulator.

This type of circulator drive has great advantages from the safety point of view. There are also considerable economic advantages, which, within limits, increase as the circulator power is raised. Savings in cost result from the cheapness of the simple high-speed turbine and gearbox in comparison with electric motors, and from the direct nature of the drive, the power supply being taken directly from the steam-raising plant and not from the main turbogenerators. It may be noted that if the drive were electrical the capacity of the main turbogenerators and their associated auxiliaries would have to be increased from 166 MW to 189 MW.

Savings in efficiency also result from the direct nature of the drive and the elimination of intermediate losses in electrical machinery and cabling (though the gearbox introduces a small loss), and—more important—from the use of reheat in the steam cycle. Economic use of the reheat principle is normally prevented in nuclear power stations by the long pipe runs and consequent high steam-pressure drops between reactors and turbines, but where the latter are situated immediately below the steam-raising units these losses are small and the advantages of reheat are more apparent. As in conventional stations these advantages take the form of: (*a*) a reduction in total steam flow; (*b*) a thermodynamic gain, since heat is given to the steam at a higher average temperature; (*c*) an improvement in turbine efficiency arising from the reduction of steam wetness in the later stages of the main turbine.

The thermodynamic gain is largely offset by the effect of the steam pressure drop in the reheater, and by the need to reduce the steam pressures slightly to accommodate the reheater while ensuring that the steam temperature is below the gas temperature at all points in the steam-raising unit. The wetness reduction is therefore by far the most important of the above factors. The gain in efficiency is quite significant and so is the effect on the turbine design, enabling long last-stage blades to be used without blade erosion.

From many points of view the best performance results when the circulator turbines consume all the high-pressure steam flow. The maximum amount of steam is reheated and the full effect of the reheat obtained. This condition was therefore aimed for in the selection of the design conditions, though for reasons of control there is a small surplus of high-pressure steam. This small quantity flows to the h.p. section of the main turbine and is used to generate useful power. Because the flow is so small the heat drop can be accommodated in a single stage of blading without serious loss of efficiency and so, although the plant works on a dual-pressure steam

cycle, the main turbines can be regarded from most points of view as single-pressure turbines working at the l.p. steam conditions, with the addition of a single stage of h.p. blading which does little to complicate the turbine design.

Arranging that the circulator turbines consume nearly all the available high-pressure steam still leaves considerable flexibility in the selection of steam conditions and circulator power. A high circulator power is obtained when the steam pressure in the low-pressure system is low, but the thermal efficiency of the main turbine is correspondingly low. If the circulator power is reduced the low-pressure-system pressure can be raised, but this lowers the feed temperature that can be obtained for a given temperature of the gas leaving the steam-raising unit and it also increases the turbine exhaust wetness. Eventually a point is reached when the loss of bled-steam feed heating and the increase in steam wetness offset the increase in steam pressure, and no increase in power output is obtained in spite of the reduction in circulator power consumption. This is illustrated by the graph in Figure 2 where the variation in overall efficiency with circulator power is illustrated for the back-pressure turbine design and for the same reactor with an electric circulator drive and the same reactor gas temperatures. Overall efficiency is defined here as the ratio of useful power to reactor heat output, useful power being the power available when the circulator requirements have been met. Under these conditions the overall efficiency of the plant with an electric drive increases continuously as the circulator power is reduced. At high circulator powers the turbine drive enables higher efficiencies to be achieved than the electric drive, though the position is reversed at low powers. In these curves the variation of circulator inlet temperature with circulator power is allowed for.

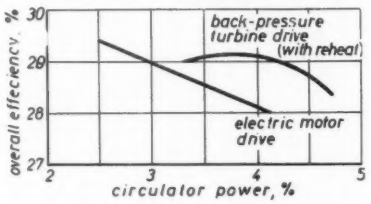


Fig. 2 Variation in overall efficiency of back pressure turbine compared with electric circulator drive

Alternative sets of gas temperatures and steam conditions were considered until the final selection was made on the basis of minimum cost per unit of power sent out, but taking into account the feed-water temperature and exhaust wetness that suited the turbine design. This point was found to be reached when the circulator power was about 4% of the reactor heat output, a higher figure than the 2½–3% that is generally found to be the optimum for electric drives and solid-rod fuel elements. It will be appreciated, therefore, that the back-pressure turbine drive is very well suited to the highly rated reactor design.

Japan's first nuclear power station

東海村

Two men supervise running and shut-down

4. CONTROL AND SAFETY

by B. H. STONEHOUSE, B.Sc.(Eng.), *and* T. J. O'NEILL, B.Sc., A.M.I.Mech.E. A.M.I.E.E.

Head of Electrical Design Section, Head of Control and Safety Section, GEC/Simon-Carves Atomic Energy Group

THE STATION is controlled from a central control room in the reactor services building. Two men supervise the running and shut-down of the station. The start-up of all plant except the reactor is carried out at points near the plant concerned. Panels in front of the main control desk carry indicators and recorders presenting information necessary for immediate control purposes, and rear-rank panels carry long-term recorders and secondary indication equipment. Direct-wire controls are used throughout and are supplemented by a comprehensive telephone system.

Overall station control

The station is designed primarily for base-load operation but load changes down to 30% of full power may be made under all conditions of fuel irradiation. The principal controlled quantity is the turbogenerator output, the reactor output being matched to the load demanded. Reactor output variations are made by changes in total gas flow, temperature conditions being maintained approximately constant by automatic movement of the control rods.

The normal start-up procedure takes 14 hours, a large part of this time being required for removal of the coarse groups of control rods at a maximum rate of 0·3 mN/s. Once significant thermal power is reached (5% of full load) the start-up rate depends on the maximum permissible rates of temperature change for fuel, pressure vessel, steam-raising units, and turbines. When operating temperatures are reached the control system is capable of changing the load at 5%/min over the range 25–100% of full load. The control system is designed to allow flexibility of operating procedure and the manual override of automatic features. The vital automatic control items are duplicated, with cross-checking features which raise an alarm and lock out the control when faulty. The station automatic control loops are shown on Figure 1.

The main turbines are fitted with h.p. steam controllers which maintain constant steam-receiver pressure, thus ensuring that this pressure is always below that of the steam supply to the gas-circulator turbines. Consequently the h.p. steam input of the main turbines is not directly dependent on the load. The l.p. steam input is speed-governed in the normal manner. As the greater proportion of the energy input is in the l.p. steam, the turbine has the basic characteristics of a speed-governed set, picking up load under conditions of falling system frequency.

Unless the reactor heat output is matched to the load demand of the main turbines, the l.p. steam pressure

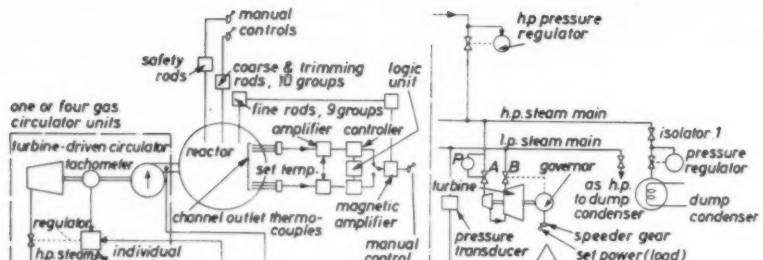


Fig. 1 Diagram of automatic station control. The measuring and control systems for coolant flow are completely duplicated and the output of one system monitors the other. A—pressure governed with overspeed override. B—speed governed

will depart considerably from its normal value. This feature is used to control the reactor heat output which is varied so as to maintain constant l.p. steam pressure. The output of a pressure transducer is compared with the required steam pressure and the amplified error signal used to drive an on/off type servo system, the output signal of which represents the required total gas flow. A similar servo system is used to produce individual required-speed signals for each gas circulator, by comparison of the computed required-flow signal with a total-flow signal obtained by summing measurements in the four main ducts. The dead-band of the pressure-error-actuated servo is set to a smaller value than that of the total gas flow, so that small variations in load demand do not vary the total flow through the reactor and hence cause variations of the fuel-element temperature. The flow servo limits the maximum rate of change of flow so that in the event of failure the run down cannot reach a dangerous rate. Figures 2 and 3 illustrate some possible fault conditions. The reactor can be run at constant power by changing the required-speed signal to manual control and the trimming of individual circulator speeds can be separately adjusted.

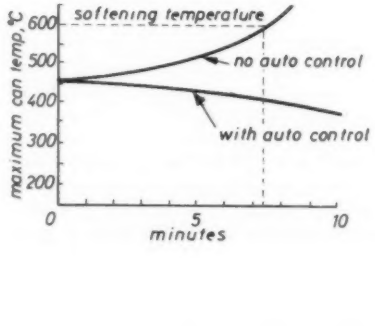
Constant-pressure controllers fitted to the h.p. line of each steam-raising unit ensure a constant-pressure feed to the gas-circulator turbine, even in the event of a fracture of the h.p. steam main. Both pressure feeds to the dump condenser are fitted with controls to maintain constant pressure in the steam mains.

Dynamic reactor characteristics

The same types of flux instabilities will be experienced in this design as are found in the civil reactors currently under construction in the UK. Such instabilities arise from two causes: (*a*) the moderator temperature coefficient, which is positive in the equilibrium state; and (*b*) the xenon poison build-up.

The rate of divergence which results depends on the time constants associated with the change of moderator temperature and of xenon build-up respectively. Both the moderator coefficient and the xenon poison build-up are sufficient to promote instability in the fundamental mode of the flux shape. Both moderator and xenon instabilities have been measured on the Calder Hall reactors. For the Tokai-Mura design, the moderator effect produces a divergence having a time constant of approximately 4 min. This means that an uncontrolled temperature disturbance of, say, 1°C would reach 2·7°C in 4 min, 7·4°C in 8 min, and so on. The xenon oscillation will have a period of about 30 h.

Fig. 2 Flow control failure—flow reduced at 10%/min



The relationship between neutron migration length and the core radius is such that in addition to the fundamental-mode instability, the two effects noted above might result in instability in the higher harmonics of the radial and aximuthal (r, θ) flux shapes. For this design, only the first azimuthal harmonic is unstable, but the time constant of divergence will be considerably greater than the 4 min of the fundamental mode.

Because of the relatively small core height compared to the radius, the increased axial neutron leakage, and the stabilizing effect of the gas stream, instability in the axial harmonics of the flux shape will not occur. Axial flux distortions will occur as a result of coarse-rod movement, but these distortions will be stable, and not divergent.

Control system

The control system must: (*a*) control any divergences induced by reactor instabilities; (*b*) allow the reactor to be started up, to change load, or remain at constant load, as required, and to be shut down at rates consistent with the safety and other operational requirements of the plant.

The net core reactivity is controlled under normal operation by movable absorber rods, and can be reduced in an emergency by a boron-ball system. The rods control approximately 8½% in reactivity and are divided operationally into twenty groups: a safety group, a coarse group, nine sector-control groups, and nine trimming groups.

The nine sector groups consist of a central region and 8 radial sector areas. The mean channel outlet gas temperature is measured in each area by thermocouples mounted in the tops of the channels. The temperature signal drives a two-term, three-state controller. In the operated state this controller has a semi-proportional output with a definite saturation value. The output controls the speed of a two-phase induction motor driving the low-frequency supply units for the sector rods. Each of the nine groups runs completely independently of the others, except for the flux coupling in the reactor, and thereby serves to control flux instability. The controllers are duplicated, with one acting as a master and one a monitor. Either may act as the master, or the system may be put under manual control. To reduce the probability of axial flux instabilities the sector rods are always operated more than 50% inserted. The rod position and the area average tem-

perature are recorded for each sector, the controllers and recorders being mounted together on panels in the main control room.

During normal load changing with the automatic controls functioning, the reactivity changes required are initiated by small changes in channel outlet gas temperatures, causing all the sector rods to move together. When effecting a load reduction a small temperature rise of up to 3°C is possible whilst the change is in progress.

The nine groups of trimming rods occupy similar areas to the sector rods. The rods are normally just short of the fully inserted position and serve to increase the range of operation of the sector groups, being repositioned when the sector rods approach the ends of their control range. The trimming groups also constitute the whole of the reactor flux flattening, the number of rods in each group being increased as the core reactivity builds up to equilibrium conditions. When large changes of reactivity are required to overcome the xenon build-up following a significant reduction in power, the trimming group is withdrawn. Normally, movement of each separate trimming group is initiated manually, but for large changes the eight outer groups can be arranged to move together.

When an emergency shut-down of the reactor is required all the rods are allowed to fall in under gravity.

The control-rod mechanisms are identical, each consisting of a permanent-magnet-rotor low-frequency synchronous machine driving a pancake winding drum through a single bevel gear. The rod is suspended on a stainless-steel rope. A separate high-resistance cage winding in the stator governs the speed during emergency shut-down.

Reactor safety under fault conditions

The principal hazard from a reactor is that of the release of large amounts of radioactive fission products. This could only happen if a large number of fuel cans were to melt, and the circumstances which might produce this are:

1. increase in reactor power;
2. increase in cold-gas temperature;
3. decrease in core gas flow.

The greatest increase in power that could arise would be that produced by uncontrolled removal of the coarse rods at their maximum rate. Even under the most adverse conditions, a time of more than 5 min would still be available between the beginning of the incident and the need to trip the reactor to avoid melting the cans.

TABLE I *Reactor shut-down trip initiators*

TRIP FUNCTIONS	NO. OF DEVICES PER GUARD LINE	CONTACT ARRANGEMENT	INITIATING DEVICE	RANGE
Main safety circuit				
Fuel-element — excess temperature	12	4 groups, each in 2-out-of-3 coincidence	transistor trip amplifier	100–600°C
Excess flux level, thermal col. No. 1	1	single	shut-down amplifier	10–700 MW
No. 2	1	single	shut-down amplifier	10–700 MW
No. 3	1	single	shut-down amplifier	10–700 MW
Short period, high level	1	single	period meter	10 kW–1000 MW 15–60 s
High outlet gas temperature	4	4 in series	transistor trip amplifier	100–600°C
Main gas valves not fully open	8	pairs of valves	limit switches	—
Circulators — loss of steam supply	4	2-out-of-4 coincidence	steam-pressure switch	10–20% of normal pressure
Pulse-counter—excess level	1	single	pulse counter	1 W–100 kW
High-level log. amplifier—excess power	1	single	high-level log. amplifier	10 kW–1000 MW
Trip button (one for three guard lines)	1	single	trip button on control desk	—
Secondary shut-down circuit	1	single	—	—
Earthquake	1	single	seismic relays	30–100 Gal vertical
Secondary safety circuit				
Reactor pressure — high negative rate of change	1	single	pneumatic R-C circuit	10 lb/in² per min and above
Earthquake	2	series	seismic relays in 2 planes	100–300 Gal horizontal
Core or vessel displacement	3	series	probe-operated switches	—

The data quoted represent improvements in the design originally tendered, and final details remain to be agreed with JAPC.

The transient behaviour of the steam-raising units is such that under no conditions could an increase in cold-gas temperature arise that was incapable of being controlled by the automatic control system; and even without this system a considerable time would elapse before any large temperatures would be achieved.

Gas-flow reductions provide the most serious potential faults, and for this reason the steam-turbine drive system is particularly satisfactory. There is virtually no incident which could give rise to failure of all circulators, the most serious circulator fault being that of reduction in speed at the maximum allowable rate. Tripping would be then required inside 10 min.

The greatest danger would undoubtedly be from failure of part of the pressure system, leading to loss of gas, reduction of gas pressure to atmospheric, and opening of the system

to atmosphere. Under these conditions can melting would obviously be particularly serious, as the release of radioactive materials would be facilitated by the fractured pressure system.

The most serious credible accident to the pressure system is failure of a main gas duct. Any other conceivable fault would be less serious than this.

Such an accident involving the main gas duct would reduce the effective core flow at a very rapid rate, and prompt tripping of the reactor would be essential. A delay of only a few seconds between the beginning of an incident and the initial entry of the trip rods into the core is required in this fault condition, so that automatic trips are essential.

Safety equipment

Two reactor safety circuits are used, each consisting of triplicated guard lines. The first group of guard-line circuits is operated by trip initiators which detect faults that are of sufficient concern to warrant reactor shut-down but that would not result in rapid melting of fuel elements. These guard lines trip the normal control rods. The second group of guard-line-circuit trip initiators is associated with major faults which require early reduction of the core reactivity. These guard lines trip the secondary shut-down devices as well as the normal control rods.

To reduce the probability of spurious operation to the absolute minimum the number of trip initiators in the second guard line is kept low, and only initiators of the highest reliability are used. Transistorized amplifiers are used for the thermocouples. Power supplies for the trip initiators and the rectified supplies for the guard-line relays are taken from three separate sources, one for each guard line.

The time elapsing between the initiation of control-rod insertion and full insertion is 8 s, the reactor power falling to 50% in approximately 2·5 s.

To ensure sufficient gas flow through the core under shut-down conditions, the steam-raising units are so placed relative to the core that a reasonable amount of natural circulation will be provided. At full pressure this alone will be sufficient to retain suitable fuel temperatures, but under atmospheric pressure conditions extra flow is provided by electrically driven pony motors, designed to produce about 1½% core flow with two out of the four motors in operation.

Equipment for CO_2 injection, using liquid CO_2, is also provided, this being intended for use in emergency, to purge the pressure system of air and then to supply a sufficient quantity of CO_2 to prevent further ingress of air to the system.

Instrumentation

Detection equipment fitted on all eight ducts provides indication in the control room of a duct fracture. The fracture indication enables the operator to shut the main valves associated with the faulty gas circuit, and the indication of reactor gas pressure enables him to judge whether this action has been successful in resealing the gas circuit.

Three thermal columns on radii at 120° intervals are installed. The output of the three ion chambers and

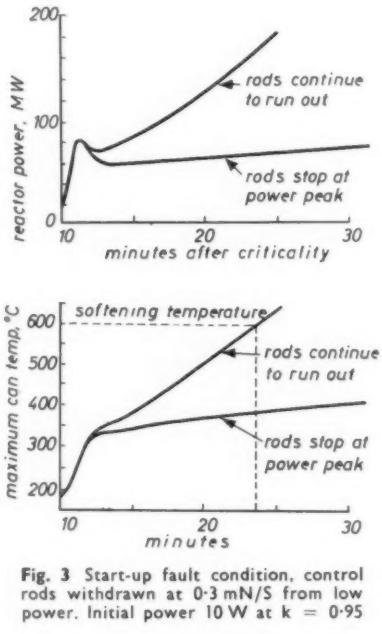


Fig. 3 Start-up fault condition, control rods withdrawn at 0·3 mN/S from low power. Initial power 10 W at k = 0·95

shut-down amplifiers associated with each column is capable of tripping the reactor, and in the event of flux instability at full power this trip acts as a back-up to the thermocouple trips. At low flux conditions during start-up the flux trip is the primary and the temperature trip the secondary feature.

The total number of temperature measurements associated with the core has been reduced to a number consistent with the use of the reactor for power production. The numbers installed are: fuel element, 150; channel gas outlet, 180; graphite, 250; pressure vessel, 230. Throughout the reactor stainless-steel-sheathed, magnesia-insulated, chromel–alumel thermocouples are used. Half of the fuel-element thermocouples are distributed in the plane of maximum fuel-element temperature, and five vertical channels are fully instrumented.

The fuel-element ther[illegible]couples associated with reactor tri[illegible] circuits are of the trailing-lead typ[illegible] but the majority are fitted with sp[illegible]g contacts on the graphite slee[illegible] which make contact with rings m[illegible]nted in the graphite moderator bloc[illegible]

Except for the thermocou[illegible]es associated with reactor trip cir[illegible]its and sector controllers, the core [illegible]hermocouples are scanned regula[illegible]y. Two scanning cycles are used, [illegible]ne of approximately one-minute period which scans 50 key points and the second of twenty-minutes period which scans the remainder. To obtain accurate operational information the data from the fast and slow scans are printed simultaneously on strip and page printers respectively.

Each temperature-measuring point is associated with one of a series of fixed alarm levels. When key points exceed the alarm level, printing is automatically initiated on the strip printer which is on the wing of the control desk.

The equipment is transistorized throughout and the thermocouple switching is carried out by mercury-wetted relays. The analogue-to-digital conversion is carried out by a repeated 'weighing' technique, the complete conversion taking approximately twenty milliseconds. The overall accuracy of the equipment, measured between input terminals and printed record, is better than ± 3°C over a temperature range of 100–600°C.

The burst-cartridge detection equipment is standard. The reactor channels are scanned every twenty minutes by 24-way motor-driven selector valves. Secondary solenoid-operated valves group the channels in sixes. Four extra precipitators scan the main ducts, act as spares, and can be used for final location and continuous monitoring of suspect channels.

About twelve hundred precipitator output signals per hour are handled by data-processing equipment. These signals are stored on magnetic tape for a period of eight hours, and are available at any time for mass print-out. Alternatively the past history of a single channel may be selected.

Two alarm levels are associated with each group of fuel channels, one an absolute alarm level and the second an alarm level which is a function of reactor load. The second level is of particular value for part-load and start-up conditions. The alarm is not prone to spurious tripping in the same manner as those operated by the rate of change of signal. Problems of tape handling are eased and the rate of response of the alarm to a steadily rising signal is improved compared with other schemes.

Japan's first nuclear power station

東海村

A large guyed derrick will lift main parts of the reactor structure into position

5. CONSTRUCTION AND ORGANIZATION

by Y. OTSUKI, M.S., B.E. *and* S. H. WEARNE, B.Sc.(Eng.), D.I.C., A.M.I.Mech.E.
Chief Engineer, Atomic Power Division, The Shimizu Construction Co. Ltd.
Project Engineer, GEC/Simon-Carves Atomic Energy Group

TOKAI-MURA is some 110 km (70 miles) north-east of Tokyo, facing the Pacific Ocean. It is 16 km (10 miles) north of Mito, the capital of Ibaraki Prefecture, and about 4 km (2½ miles) south of Kuji Harbour. Mito has a population of 150,000, and Kuji Harbour about 13,000.

The site for the nuclear power station is next to the Japanese Atomic Energy Research Institute. The east side of the site faces the Pacific Ocean; the west and south sides are surrounded by sand dunes which are thickly covered by pine plantations. The graded level of the site will be 8-m (26½-ft) elevation above the mean tidal level in Tokyo Bay, which is the datum level for Japan. By comparison the annual maximum of the high-tide level near the site is slightly less than 2 m (6½ ft) above datum. Because of the long, straight shape of the coast, Japanese geophysicists conclude that there will be no probability of any tidal-wave calamity, but typhoons are a possibility each autumn.

As for the geology of the site, it was found fairly difficult to reach a final conclusion, in spite of many test borings which were conducted by the JAPC. However, it has been made clear that a mud-stone layer definitely of tertiary formation lies uniformly below the level of − 15 m (− 49 ft). Above this lies coarse gravel, about 8-m (26½-ft) thick, loose gravel for about 7 m (23 ft)—supposed to have plenty of ground water—and finally loam and loose sand up to the present natural ground level.

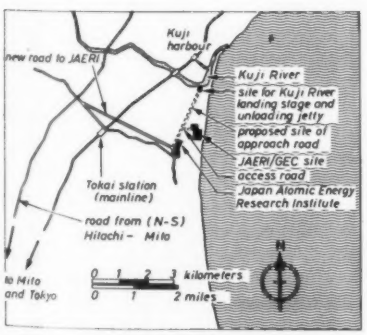

Kuji harbour
new road to JAERI
Kuji River
site for Kuji River landing stage and unloading jetty
proposed site of approach road
JAERI/GEC site access road
Japan Atomic Energy Research Institute
Tokai station (mainline)
road from (N-S) Hitachi – Mito
to Mito and Tokyo
0 1 2 3 kilometers
0 1 2 miles
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Fig. 1 Sketch map of approaches to Tokai-Mura site

The coarse gravel layer, below the level of − 7 m (− 23 ft), was at first considered to be the same formation as the layer of tertiary formation under the JAERI site. It would therefore have been sufficiently consolidated to support the load of the reactor structure. However, further boring tests, together with a load test, revealed that this layer was erratic. Detailed soil studies showed that the gravel layer under the reactor site was alluvial and contained lens-shaped loam or clayish formations which were not fully compacted. Therefore, it was finally decided by the JAPC to provide caissons which would transmit the load directly to the mud-stone stratum.

The station has been laid out as a single-reactor unit with two generating sets in the turbine hall. No specific provisions have been made for a second reactor or extensions to the turbine hall, but ancillary buildings, such as the administration and decontamination blocks, have been situated so as to be suitable for use if a second unit is added in the spare area which will be available in the northern part of the site.

The station presents the usual problem in the interleaving of civil and mechanical work on a very tight time scale. When first considered, the construction method was based on the use of a Goliath crane, in order to achieve the maximum possible amount of prefabrication of pressure-vessel components away from the reactor structure. A re-examination of the problem resulted in a decision to use a large guyed derrick. This crane has a main lift of 125 tonnes at 60 m (200 ft),

Fig 2 The site is being cleared by hand

and an auxiliary lift of 25 tonnes. The main mast will be over 115-m (380-ft) high and the length of the main boom is about 75 m (250 ft). The derrick will stand on a tripod pedestal 25-m (83-ft) high, over the cooling-pond foundations.

It will not be possible to lift in one piece the heaviest parts of the plant, such as the steam-raising-unit vessels and the moderator support grid. These will instead be lifted in sections, and closing welds made *in situ*. This makes the construction programme a little longer but is justified by the economies achieved.

Reactor pressure-vessel plates will be shipped from the UK. The pressed plates will be welded into two-plate panels and then into top and bottom heads and partial tiers. These components will then be assembled and welded *in situ* inside the biological shield. Stress-relieving will be carried out by electric heating, and pressure-testing pneumatically.

Other major lifts for the guyed derrick are the vessels and bridge beams for the two charge machines. After erection of these the internals will be completed *in situ*, utilizing the permanent maintenance facilities in the top-shield area.

INDUSTRY'S CONTRIBUTION

A substantial proportion of the work will be provided under separate contract let independently by JAPC. For some of this work GEC are providing design services. Work to be handled in this way includes the circulating-water system and civil work in the turbine hall.

GEC are the main contractors for the reactor unit and generating plant. Associated with GEC for this work is the First Atomic Power Industrial Group, a consortium headed by the Fuji Electric Manufacturing Co. Ltd.

A subsidiary of GEC—the British General Electric Company of Japan Ltd. has been formed to maintain close liaison with JAPC under the direction of Mr. R. J. Smith.

These firms will build Tokai-Mura

The General Electric Co. Ltd. Turbogenerator sets, gas circulators and turbines, fuel-handling equipment and charge machines, control-rod mechanisms, reactor instrumentation, burst-cartridge detection equipment, and reactor switch gear.

Simon-Carves Ltd. Design and supervision of construction for civil works, steam-raising units, and auxiliary gas circuits.

Fuji Electric Manufacturing Company Construction of reactor pressure vessel, grid, moderator structure, and installation of reactor auxiliaries and cabling.

Kawasaki Dockyard Company Construction of steam-raising units, gas ducts, main condensor, and shield cooling.

Shimizu Construction Company Reactor caissons and civil construction.

Powell-Duffryn Carbon Products Ltd. Graphite machining.

Maschinenfabrik Ausburg-Nürnberg A.G. 125-ton erection derrick.

Kobe Steel Co. Construction of CO_2 plant.

Colvilles Ltd. Supply of reactor-vessel plate.

PRINCIPAL DATA AND PERFORMANCE

The design as presented is in metric units though equipment supplied from the United Kingdom has in general been designed to British units. The data quoted represent improvements in the design originally tendered, and final details remain to be agreed with JAPC.

Performance

Maximum can surface temperature	454°C (850°F)
Reactor heat output	570 MW
Gross power generated (at C.W. temperature of 20°C)	166 MW
Net power sent out	158 MW
Net station efficiency	27·7%

Fuel

Fuel material	natural uranium, hollow rods	
Canning material	Magnox	
Type of finning	straight longitudinal fins, helical swirlers	
Type of support	independent in graphite sleeves	
Fuel-rod outside dia.	40·8 mm	(1·606 in.)
Fuel-rod inside dia.	23·7 mm	(0·934 in.)
Fuel-rod length	714 mm	(28·1 in.)
Elements/channel	8	
Uranium in reactor	172 tonnes	

Core data

Diameter of active core	11,280 mm	(37 ft 0 in.)
Height of active core	6630 mm	(21 ft. 9 in.)
Overall core diameter	12,800 mm	(42 ft 0 in.)
Overall core height	8150 mm	(26 ft 9 in.)
Graphite-sleeve bore		
inner channels	102 mm	(4·0 in.)
outer channels	97 mm	(3·8 in.)
Lattice pitch	236 mm	(9·3 in.) equilateral triangles
No. of fuel channels	1916	
No. of control and spare channels	168	
Mean thermal-neutron flux in uranium at centre of core (Westcott Convention)	$2{\cdot}0 \times 10^{13}$ n/cm² sec	
Radial averaging factor	0·75	
Axial averaging factor	0·70	
Final flattened radius	2650 mm	(8 ft 8in.)

Initial lattice constants	Cold	Hot
Thermal-utilization factor	0·5798	0·5747
Resonance-escape factor	0·8924	0·8849
Fast fission factor	1·0317	1·0317
Thermal-fission factor	2·0171	2·0146
Multiplication constant	1·0768	1·0570

Reactor vessel

Shape	spherical	
Material	fine-grain, Al-killed steel	
Internal diameter	18,900 mm	(62 ft 0 in.)
Thickness	83 mm	(3¼ in.)
Maximum working pressure	14·4 kg/cm²	(205 lb/in² g)
Design pressure	16·2 kg/cm²	(230 lb/in² g)

Main control system

Type	vertical rods entering reactor from above	
No. of control rods	109	
Material	boron-steel	
Diameter of rods	70 mm	(2·75 in.)
Length	6400 mm	(21 ft)
Reactivity controlled	approx. 8·5%	

Secondary shut-down system

Type	boron-steel balls	
No. of channels	44	
Diameter of balls	approx. 16 mm	(⅝ in.)
Reactivity controlled	approx. 4%	

Coolant

Coolant gas	carbon dioxide	
Reactor flow rate	2720 kg/s	(6000 lb/s)
Pressure at reactor inlet	14·3 kg/cm²	(204 lb/in² g)
Temp. at reactor inlet	203°C	(397°F)
Temp. at reactor outlet	398°C	(748°F)

Coolant circuits

No. of circuits	4	
Duct internal diameter	1820 mm	(5 ft 11½ in.)

Coolant circulators

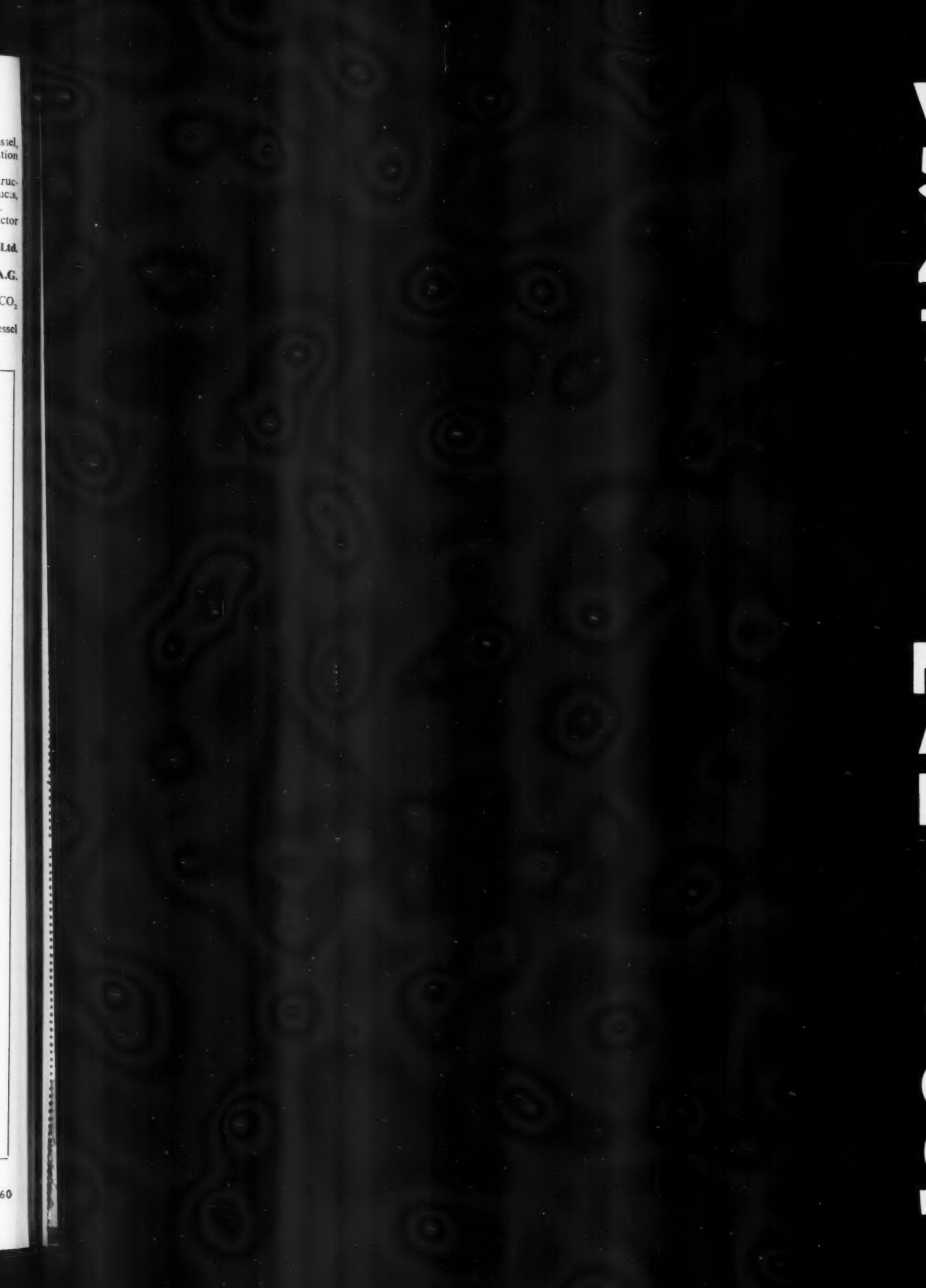
No. of circulators	4	
Type of circulator	centrifugal, single-stage, vertical-shaft	
Type of drive	back-pressure steam turbine	
Mass flow/circulator	690 kg/s	(1522 lb/s)
Inlet gas pressure	13·3 kg/cm²	(189 lb/in² g)
Inlet gas temperature	196°C	(384°F)
Pressure rise	1·1 kg/cm²	(16 lb/in²)
Power consumption (turbine shaft)	5500 kW	(7400 hp)
Steam consumption	105,000 kg/h	(232,000 lb/h)
Speed (circulator shaft)	1200 rev/min	
Speed (turbine shaft)	7700 rev/min	

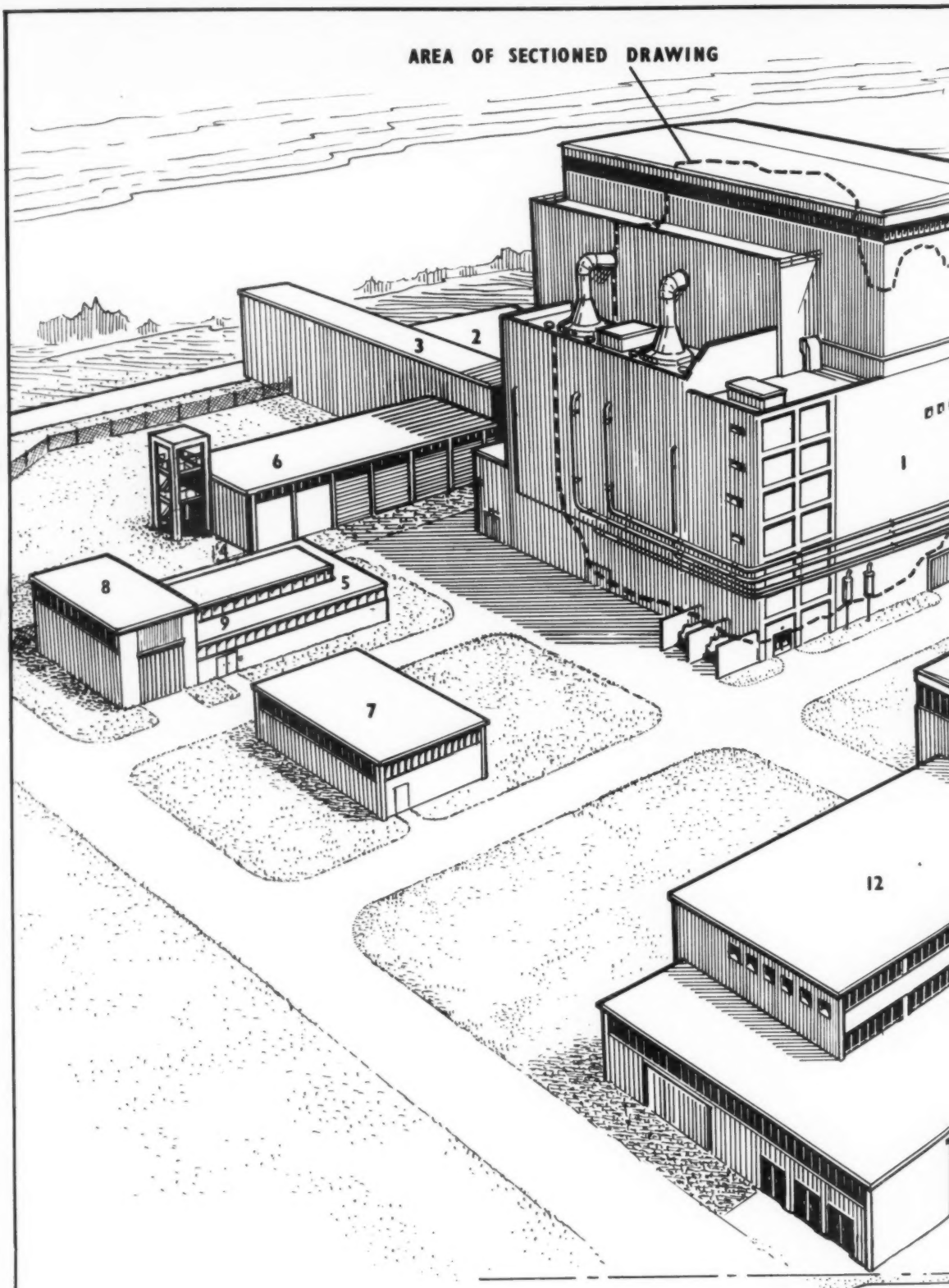
Steam-raising units

No. of units	4	
Type	dual-pressure with reheater	
Internal diameter	6260 mm	(20 ft 6 in.)
H.P. steam generated per unit	114,500 kg/h	(252,000 lb/h)
L.P. steam generated per unit	63,500 kg/h	(140,000 lb/h)

Turbogenerators

No. of sets	2	
Power generated/set	83,000 kW	
Speed	3000 rev/min	
H.P. steam flow per set	18,600 kg/h	(41,000 lb/h)
H.P. steam pressure at stop valve	63 kg/cm²	(895 lb/in² g)
H.P. steam temperature at stop valve	379°C	(714°F)
L.P. steam flow per set	334,000 kg/h	(737,000 lb/h)
L.P. steam pressure at stop valve	19 kg/cm²	(270 lb/in² g)
L.P. steam temperature at stop valve	364°C	(687°F)
Final feed temperature	72°C	(162°F)





1. Reactor
2. Cartridge cooling pond
3. Element discharge bay
4. Contamination area change room
13. Fire station, garage and vehicle hangar
14. Pipe bridge
15. Administration
16. Canteen

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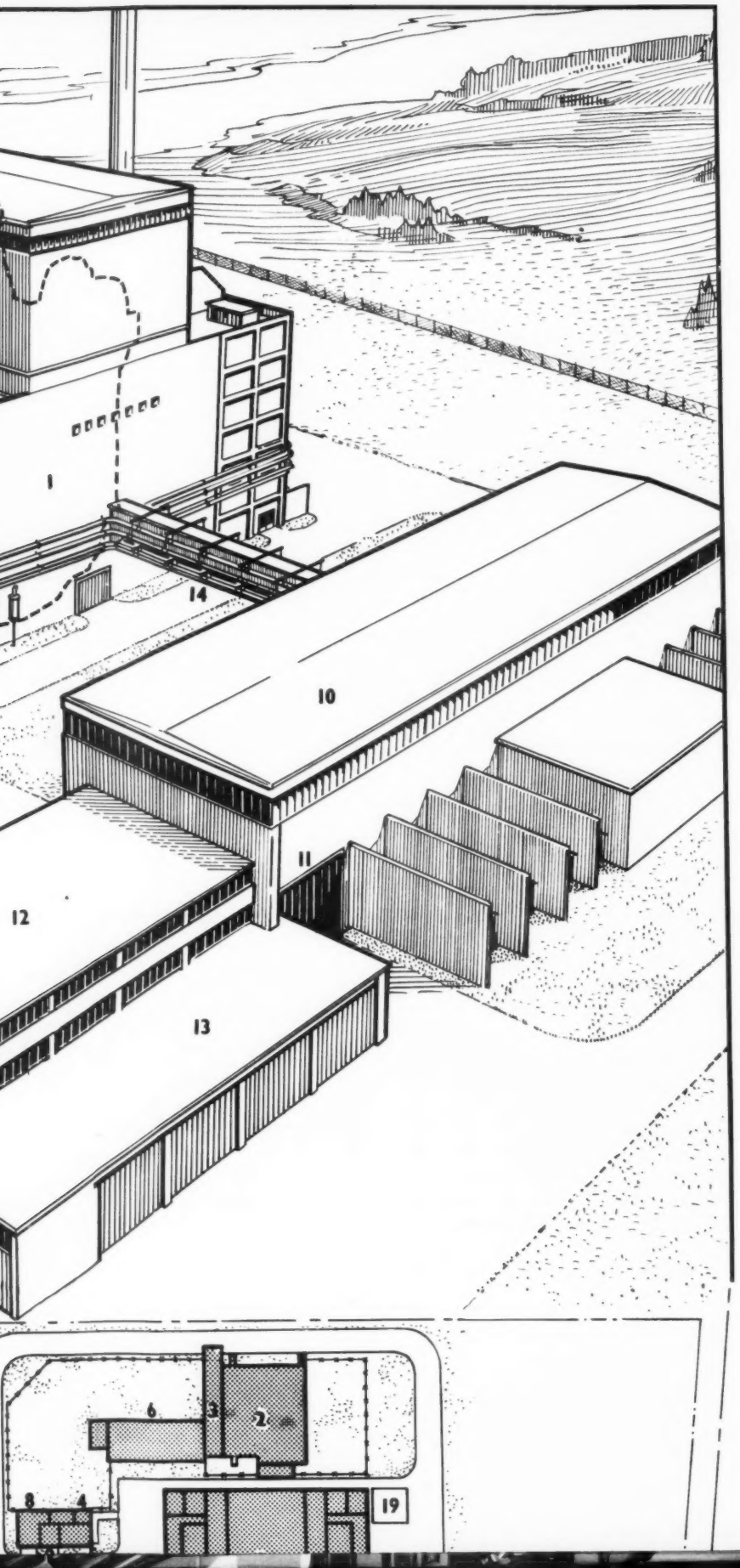

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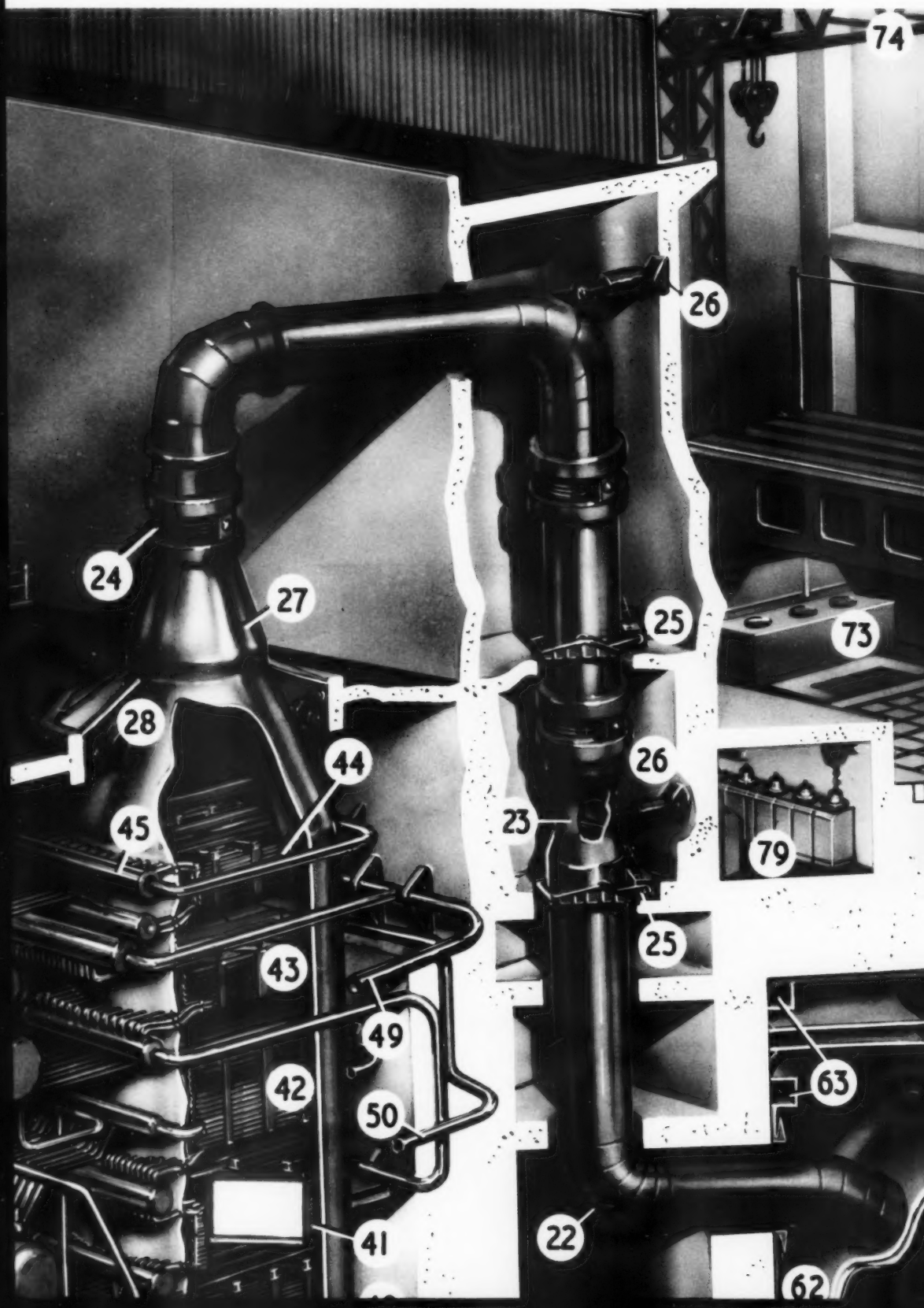
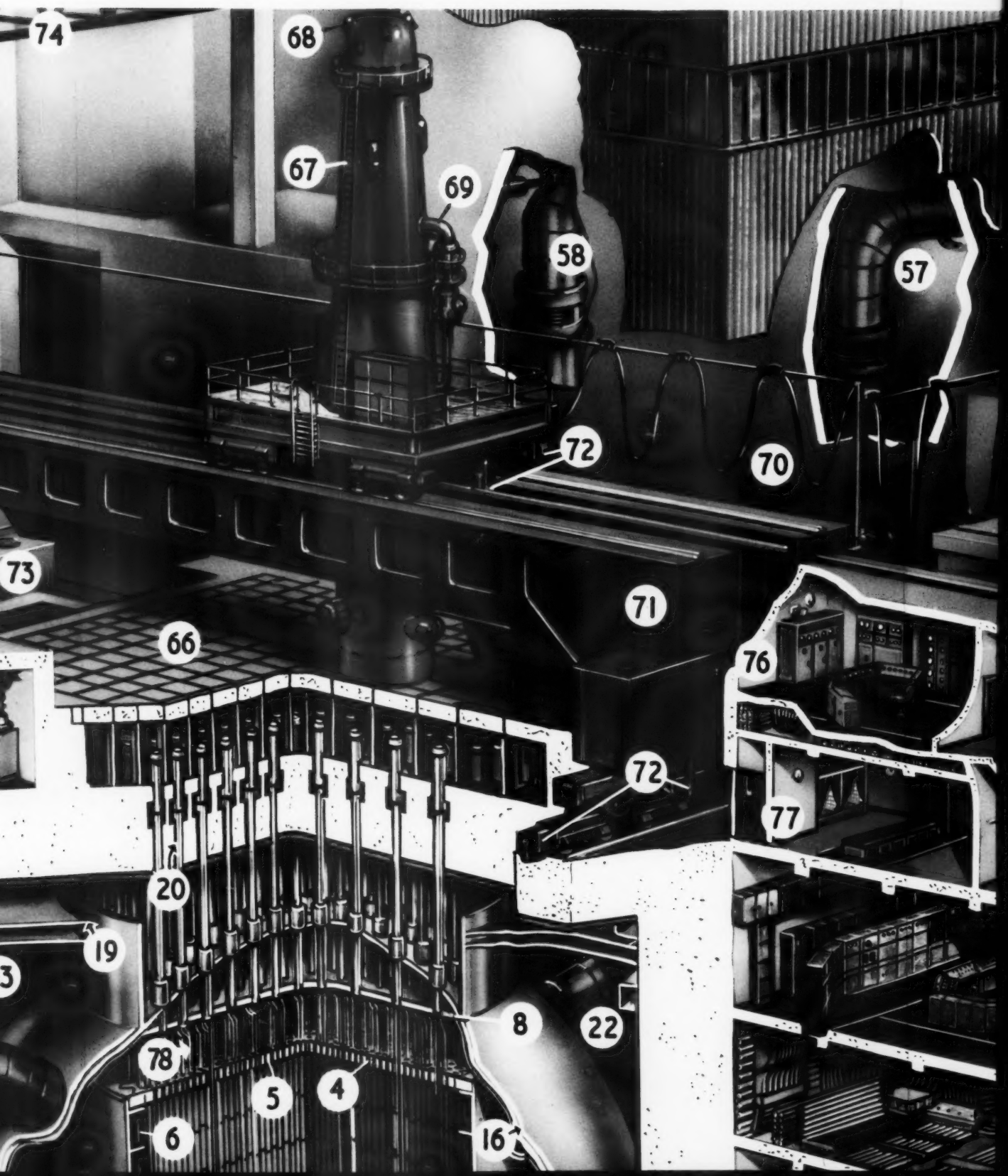


THE JAPAN ATOMIC POWER COMPANY
Nuclear Power Station



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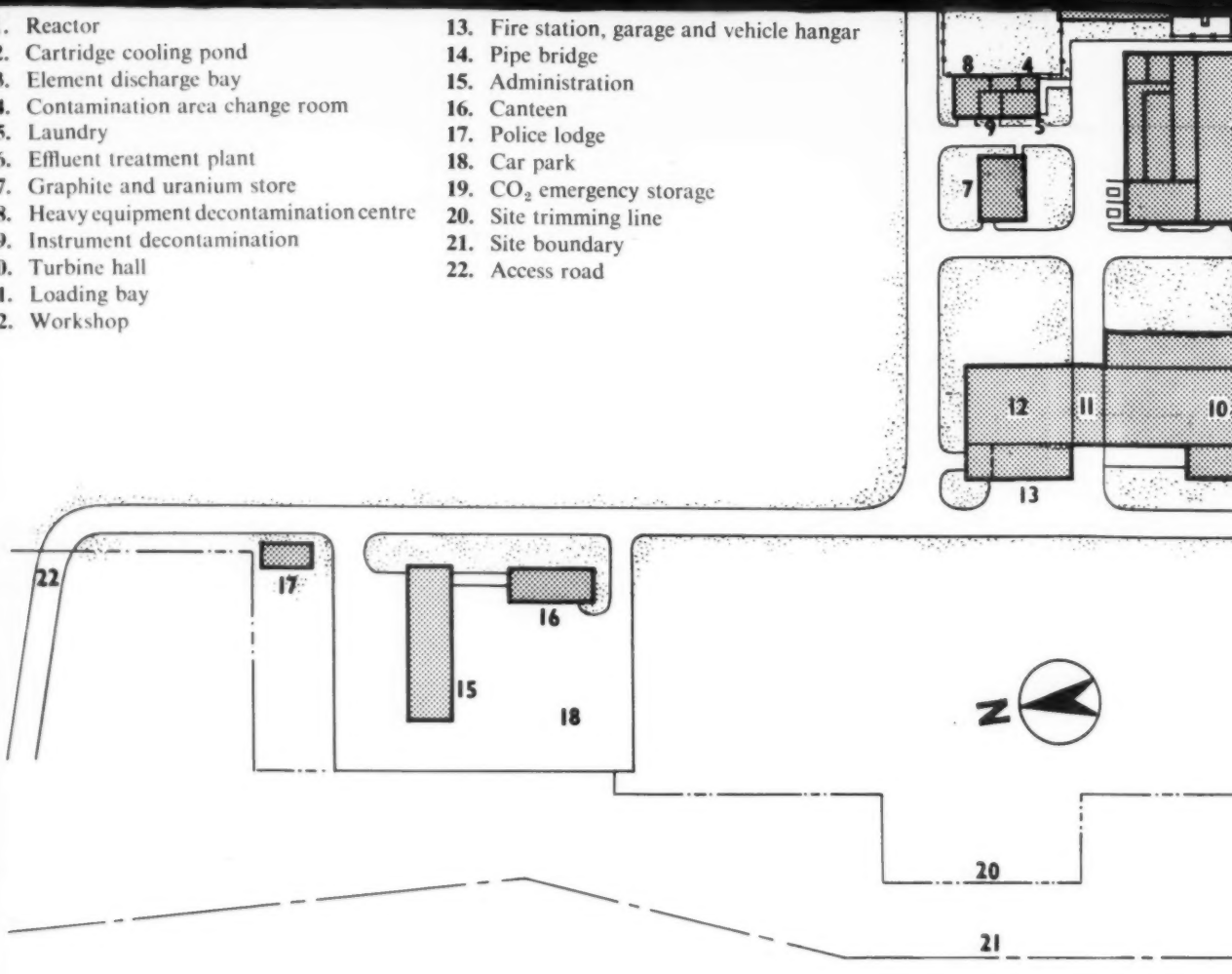
1. Reactor
2. Cartridge cooling pond
3. Element discharge bay
4. Contamination area change room
5. Laundry
6. Effluent treatment plant
7. Graphite and uranium store
8. Heavy equipment decontamination centre
9. Instrument decontamination
10. Turbine hall
11. Loading bay
12. Workshop
13. Fire station, garage and vehicle hangar
14. Pipe bridge
15. Administration
16. Canteen
17. Police lodge
18. Car park
19. CO_2 emergency storage
20. Site trimming line
21. Site boundary
22. Access road



DESIGNERS AND MAIN CONTRACTORS FOR THE REACTOR UNIT AND GENERATING PLANT

The General Electric Company Limited of England

The British General Electric Company of Japan was formed to handle the contract work in Japan. Associated with G.E.C. is the First Atomic Power Industrial Group of Japanese industrial firms, headed by the Fuji Electric Manufacturing Company.

THE GENERAL ELECTRIC CO

SIMON-CARVES LTD

FUJI ELECTRIC MANUFACTUR

KAWASAKI DOCKYARD COM

SHIMIZU CONSTRUCTION CO

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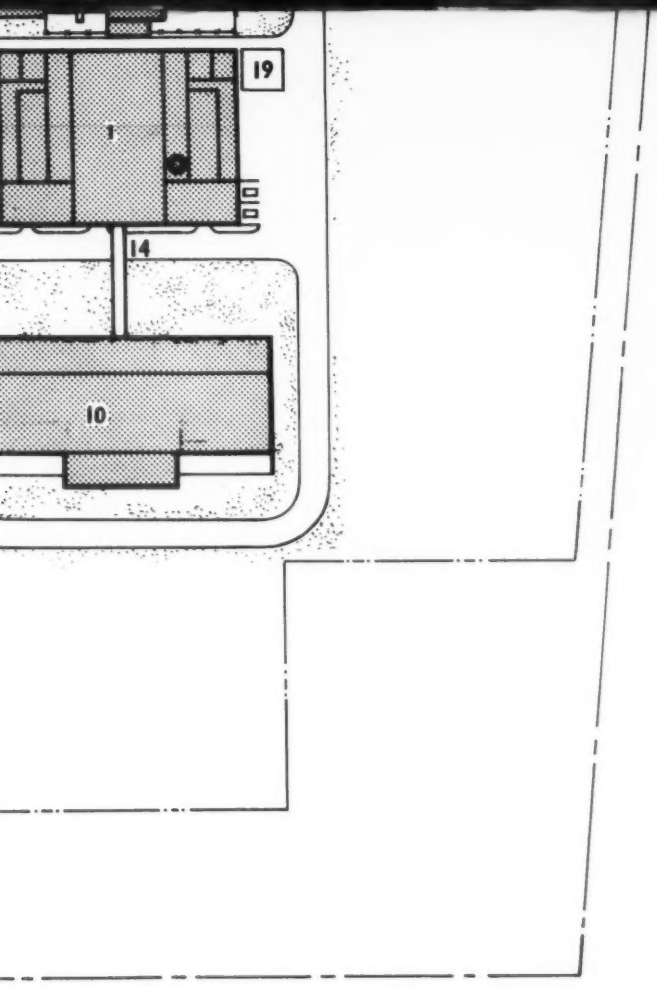
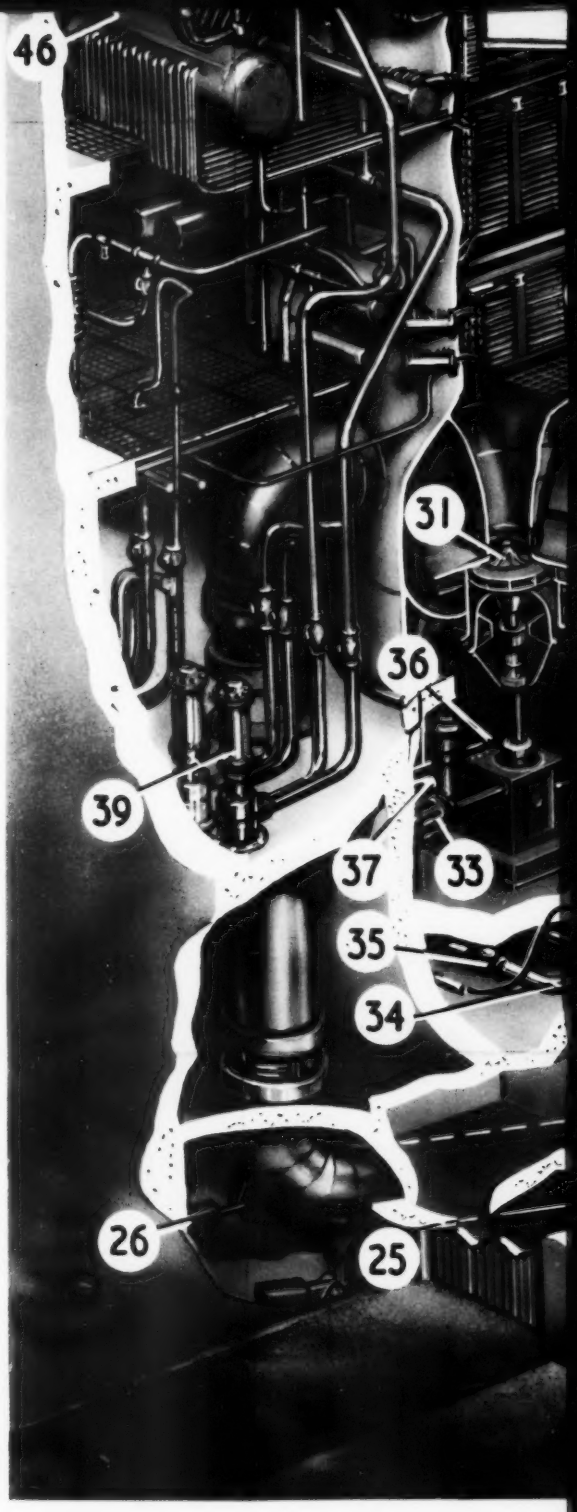
Nuclear Power





Main Allocation of Work

ELECTRIC CO LTD	Turbo generator sets, gas circulators and turbines, charge machines and fuel-handling equipment, control-rod mechanisms, reactor instrumentation, burst-cartridge detection equipment, and reactor switchgear.
LTD	Design and supervision of construction for reactor civil works, steam-raising units, and auxiliary gas circuits.
MANUFACTURING COMPANY	Construction of reactor pressure vessel, grid, and moderator structure; installation of reactor auxiliaries and cabling.
KYARD COMPANY	Construction of steam-raising units, gas ducts, main condenser, and shield cooling.
TRUCTION COMPANY	Reactor caissons and civil construction.

1. Reactor core
2. Fuel elements
3. Control rods
4. Channels
5. Charge pans
6. Restraint beams
7. Core restraint cylinder
8. Boron shield
9. Support plates
10. Diagrid
11. Debris collector cones
12. Debris collector

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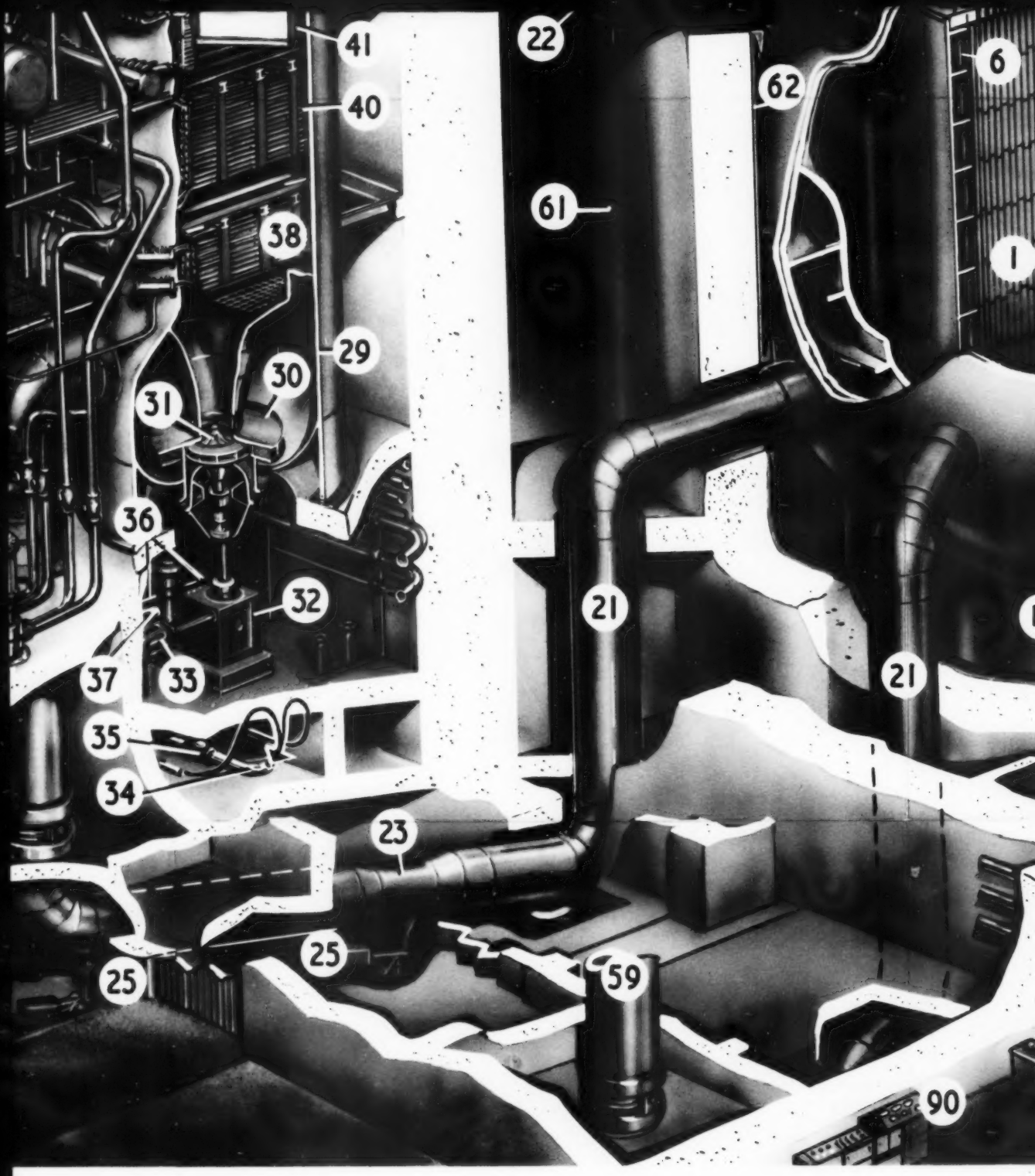

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14. Apertures for gas
15. Pressure vessel
16. Pressure-vessel lagging
17. Primary gas seal
18. Secondary gas seal
19. Pressure-vessel earthquake restraint
20. Charge/discharge standpipes (used also for control rods and secondary shut-down devices)
21. Cold gas ducts
22. Hot gas duct
23. Gas valves
24. Hinged bellows units
25. Duct counterweight supports
26. Duct earthquake restraints
27. Steam-raising unit No. 4
28. S.R.U. earthquake restraint
29. S.R.U. pressure vessel
30. Gas-circulator diffuser
31. Gas-circulator impeller
32. Gas-circulator turbine drive
33. Pony motor
34. Steam pipe to circulator-turbine governor from s.r.u.
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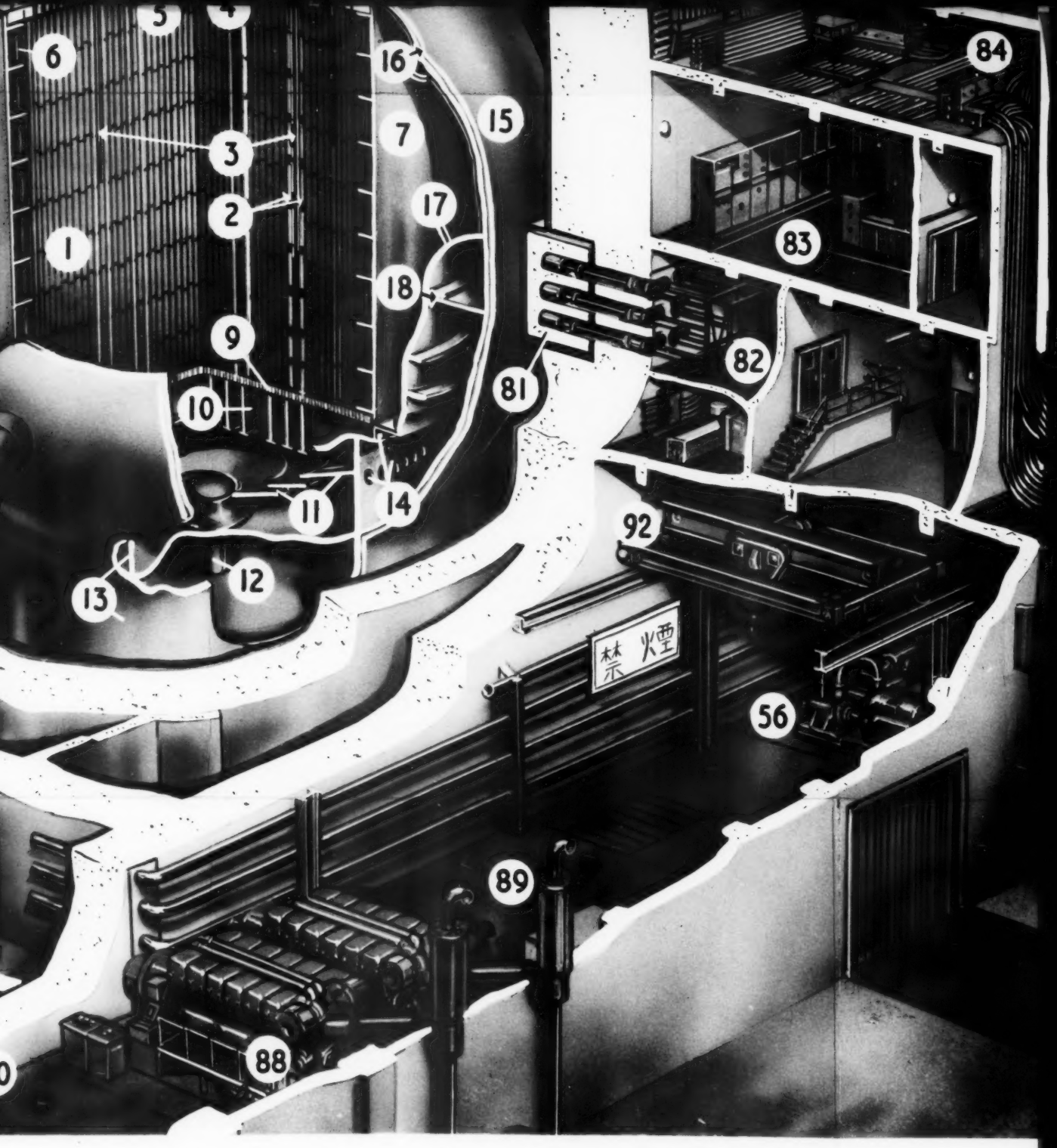

35. Steam strainer
36. Circulator-turbine steam inlets
37. Circulator-turbine exhaust
38. H.P. and L.P. mixed economizer bank
39. Boiler circulating pumps
40. L.P. evaporator bank
41. H.P. evaporator bank (lower)
42. H.P. evaporator bank (upper)
43. L.P. superheater bank
44. H.P. superheater bank
45. H.P. superheater outlet header
46. L.P. main steam drum
47. H.P. main steam drum
48. H.P. dry steam drum
49. L.P. steam delivery
50. H.P. steam delivery
51. Cable and pipe bridge to turbine hall
52. L.P. steam pipes
53. H.P. steam pipes
54. Steam pipe to dump condensers
55. Feed-water pipe
56. Feed pumps
57. Hot gas duct to s.r.u. No. 1
58. Hot gas duct to s.r.u. No. 2
59. Cold gas duct to s.r.u. No. 3
60. Ventilation fan for s.r.u. enclosure
61. Biological shield
62. Shield-cooling platework
63. Shield-cooling exhaust ducts
64. Shield-cooling discharge ducts
65. Shield-cooling fan
66. Supplementary top shield
67. Charge machine
68. T.V.-camera viewing dome
69. Charge-machine coolant circuit
70. Charge-machine supply cable

duct to s.r.u. No. 3	71.
n fan for s.r.u. enclosure	72.
l shield	73.
oling platework	74.
oling exhaust ducts	75.
oling discharge ducts	76.
oling fan	77.
ntary top shield	78.
achine	79.
era viewing dome	80.
achine coolant circuit	81.
achine supply cable	82.

71. Charge-machine bridge
72. Earthquake locks
73. Shafts to fuel-handling rooms
74. Charge-machine crane
75. Charge-machine maintenance bay
76. Charge-machine control room
77. Change room to top shield area
78. Burst-cartridge-detection sample pipes
79. B.C.D. selector valves.
80. B.C.D. circulators
81. Thermal column
82. Ion-chamber room
83. Control-rod supplies
84. Cable distribution floor
85. Cable duct
86. Station control room
87. Shift engineers' office
88. Emergency diesel generators
89. Diesel exhaust
90. Diesel control board
91. Station diesel board
92. Maintenance crane
93. Motor control units
94. Battery room
95. Lift motor room

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STUDENTS' NOTEBOOK

GROUNDWORK—Materials

Why is Wigner energy a graphite problem?

When reactor grade graphite is subjected to neutron bombardment, some of the atoms are knocked out of their normal positions, energy being created during the movement. These displaced atoms can move about inside the material and may find their way back, either to the original or some other position. When this happens the stored (Wigner) energy is partially or totally released in the form of heat.

The length of time taken for this release of energy varies considerably, because of differences in the distribution pattern of the displaced atoms and the innate properties of the various types of displacement. This period, or 'lifetime', can vary considerably at any particular temperature, from a fraction of a second to some hundreds of years. The total stored energy builds up progressively with irradiation dose, but the important factor about this phenomenon is that the lifetime of displaced atoms becomes progressively shorter as the temperature of the graphite increases. Where atom repositioning is relatively quick in the temperature range 30°–100°C, lifetime is reduced by a factor of about 2·5 for each 10°C rise in temperature. A lifetime of one year at 30°C, for instance, can be transformed to about 24 hours at 100°C.

The release of heat takes place mainly in two regions: in the range 100°–200°C and at 1200°C, but it is only the first region that is of practical importance when the safety of graphite moderated reactors has to be considered. Irradiation temperatures near 350°C and above result in only one hundredth part of the stored energy generated at 30°C for the same irradiation dose. At 400°C the stored energy content is about 18 cal/g as compared with several hundred at 30°C.

The release of stored energy in the form of heat can help further release in adjacent areas, an effect that is cumulative until all the stored energy is released. In the absence of cooling, the release of energy in the 100°–200°C range will have the total effect of raising the graphite temperature into the range 300°–450°C. For the safe operation of a graphite moderated reactor it is essential to release the Wigner energy under controlled conditions so as to avoid an undesirable increase in graphite temperature that might cause rapid oxidation of the graphite, a mechanism which in turn creates further heat. This could cause extensive damage to fuel elements and other materials.

BOOKLIST—Nuclear Chemistry

Nuclear Chemical Engineering. M. Benedict and T. H. Pigford. McGraw-Hill 1957. A comprehensive treatment of fuel processing and isotope separations.

Chemical Processing of Nuclear Fuels. F. S. Martin and G. L. Miles. Butterworths 1958. A good description of the chemistry of nuclear fuel processes which includes high temperature treatment but very little technology.

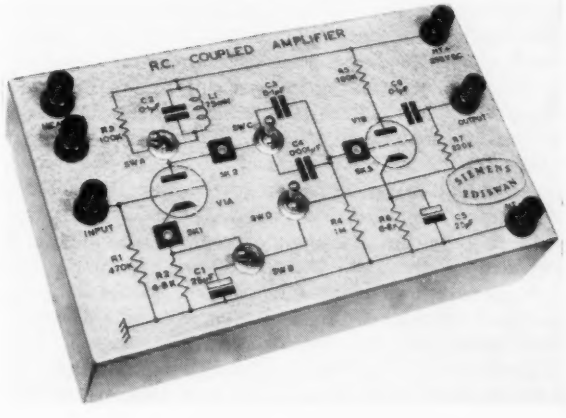
Disposal of Radioactive Wastes. K. Saddington and W. L. Templeton. Newnes 1958. A brief treatment but well written.

Ion Exchange Technology. F. C. N. Nachod and F. C. Schubert. Academic Press 1956. A good practical treatment covering large-scale use of ion-exchangers and applications to radioactive substances.

Chemistry of Nuclear Power. J. K. Dawson and G. Long. Newnes 1959. A well-written book for the non-specialist. The Pergamon Progress Series should also be consulted, e.g. Progress in Nuclear Energy, Series III—Process Chemistry.

TEACHING ELECTRONICS

A series of practical training aids to basic electronic theory have been designed by AEI in collaboration with Northampton Polytechnic, operating in the audio frequency range. The circuit diagram of each major unit is printed on the chassis, terminals or switches are mounted where they occur in the circuit. Wiring and components can be viewed through a Perspex base beneath the chassis.



In this Amplifier Unit switches alter coupling capacitor values, introduce feed-back or bring a tuned anode load into circuit. Use includes phase change measurement and current and voltage feedbeck effects

NEWSBRIEFS

● Ohio State University is to have a 10kW Lockheed pool-type reactor for student training in reactor physics and engineering.

● Six research fellowships are to be awarded this summer to Texas graduate students for work at General Dynamics. They will assist in theoretical and experimental research in plasma physics, including experiments with pinch discharge and shock tubes.

● The International School at Argonne, now an International Institute, allows foreign scientists and engineers to participate in the work on research projects with Argonne staff members.

UK COURSES

Northampton College of Advanced Technology. Six lectures on secondary surfaces for heat exchangers. Good knowledge of heat transfer required. Lectures, which commence on March 2, will be given on Wednesday evenings at 7.00 p.m.

Harwell. An international course on nuclear energy has been arranged by the European Nuclear Energy Agency, from July 4 to 15, and will cover the technical, economic, and industrial aspects.

Battersea College of Technology. Metallurgists, whose academic training was completed some years ago, may well need revision in fringe subjects. Lecture courses are being held lasting 3–4 days and the one for Easter Vacation covers 'the Structure of Metals and Alloys'.

Imperial College, London. A summer school in Health Physics (Radiation Protection) of two weeks' duration starts on Monday, July 4. The courses, which include practical work and visits, should interest university radiation protection officers, industrial safety officers, medical officers of health, factory inspectors and others concerned with radiation protection. Fee: 25 gns.

Imperial College, London. Reactor Fuel Element Technology. It is still possible to enrol for the remaining lectures on the afternoons of March 3, 10 and 17. Emphasis is on industrial problems; aspects to be covered include AGR, fast reactors, Dido-type elements, HTGC, OMR, and LMFR reactors.

Royal College of Science and Technology, Glasgow. Symposium on Nuclear Reactor Containment Buildings and Pressure Vessels. May 17 to 20, 1960. Fee: £6.6.0.

After eighteen months development work on this new technique several plants are expected to be in operation in the near future

Uranium tetrafluoride manufacture with fluidized solid techniques

by E. HAWTHORN, F.R.I.C.
Works Manager, Fluidization, UKAEA Springfields Works

AFTER uranium has been dissolved into nitric acid and purified it is passed through four long tube, natural circulation, evaporators working in series (Figure 1). Steam and uranyl nitrate solution are fed to the first evaporator, the solution being contained within the tubes and the steam on the outside. Water removed here as steam from the uranyl nitrate passes into the shell side of the second evaporator where it is used as the heating medium. Similarly water removed as steam in the second evaporator is used as the source of heating for the third and so on through the evaporator system. To increase the pressure differential throughout the system the fourth evaporator operates under vacuum obtained by a Nash vacuum pump. The evaporators, therefore, work with forward feed, the pressure differential in the system driving the uranyl nitrate solution from the first to the fourth. It was decided to use this type of feed in preference to a counter-current process in order to avoid the need for pumping hot concentrated solutions of uranyl nitrate which, from experience, has proved to be difficult. Concentrated liquor from the fourth evaporator passes into a storage tank, the contents of which are maintained at a temperature of about 90°C to prevent crystallization of uranyl nitrate. To prevent loss of the nitrate as entrained droplets in the vapour phase, the evaporators are fitted with separators filled with stainless steel raschig rings. Between each pair of evaporators there is a control valve operated by a level recorder controller so that, as the level falls in the fourth evaporator when the uranyl nitrate is removed, the level controllers in the previous evaporators open the control valves to restore the balance.

At the UKAEA's Springfield Works a large-scale pilot plant for the preparation of uranium tetrafluoride (green salt) is now being operated.
The broad sequence of processes is as follows: a solution of uranyl nitrate is first converted to uranium trioxide by thermal decomposition. The trioxide is reduced to the dioxide with hydrogen and the dioxide is finally converted to the tetrafluoride by the action of hydrofluoric acid. Associated with the fluidized solids reactors is a quadruple effect evaporator which is used to remove most of the water from the uranyl nitrate solution.

Three variables control the operation of the evaporators: **1.** the flow of steam, **2.** the flow of uranyl nitrate, and **3.** the pressure differential throughout the system. It has been found at Springfields that for a given throughput the most satisfactory method of operation is to set the pressure in the fourth evaporator, to set the flow of steam to the first and, to control the flow of uranyl nitrate to the first evaporator by the level recorder controller in it. The steam pressure to the first and the pressure in the fourth evaporator are kept constant by pressure recorder controllers.

The uranyl nitrate is preheated almost to its boiling point before it enters the first evaporator using waste heat from the evaporator system. The first heat exchanger is heated with the waste steam leaving the fourth evaporator, the second one with the condensate from the calandrias of the second, third and fourth evaporators, and the third preheater is heated with the steam from the calandria of the first evaporator.

One of the problems encountered during the start-up period was the poor heat transfer coefficient for each evaporator. It was decided at this time to start with the calandria tubes full of liquor to prevent crystallization taking place within the tubes. It was later found, however, that this did not occur and the levels were gradually reduced until only one third of the tubes were submerged. The overall heat transfer coefficients in the second, third, and fourth evaporators were improved considerably.

DENITRATION

This reaction, used for converting uranyl nitrate into uranium trioxide by thermal decomposition, is illustrated in Figure 2. The stainless steel reactor is cylindrical with a conical base. The diameter is increased at the top to reduce the gas velocity in this region, thereby reducing the load on the filters. These are made of sintered stainless steel and hang from the top of the reactor to project into the expanded portion for about 4 ft. The compressed air used for fluidizing the solids together with the gaseous by-products of the reaction, oxides of nitrogen and steam, pass through the filters (which hold back the uranium trioxide) and are finally discharged to waste through a heat exchanger and a water jet condenser. These gases exchange their heat with the compressed air used for fluidizing the bed of trioxide.

Transfer of heat into the reactor presented a problem for two reasons: the limit set on the reactor wall temperature by the adverse effect of high temperature on

uranium trioxide, and the limited surface area of the reactor. To overcome these problems the effective surface area for heat transfer was increased by inserting immersion heaters through the base of the reactor. These and a muff heater round the outside of the vessel are both heated by electricity. The problem of heat transfer to the denitrator was the reason for using an evaporator to remove as much water as possible from the uranyl nitrate before the denitration process.

The concentrated uranyl nitrate solution is injected below the top level of the bed of trioxide by means of spray guns which project into the bed of solids to a distance of 9 in. The spray guns work on a similar principle to a paint sprayer: uranyl nitrate solution is forced under pressure through a small nozzle and is finally atomized by a jet of compressed air which travels concentrically with it, the two meeting at the tip of the gun.

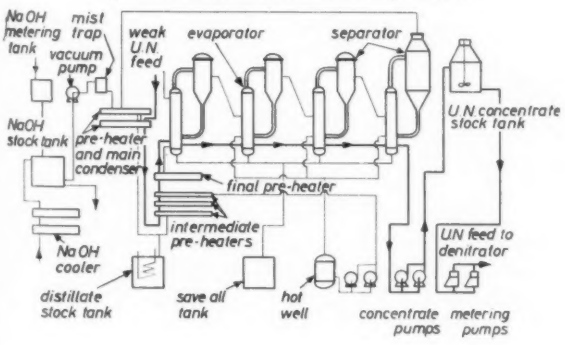
The solids are removed from the bed by means of a standpipe and this in turn controls the level of solids inside the reactor. Uranium trioxide overflowing from the top of the bed through this standpipe is lifted into the hoppers situated above the reactors by means of an air operated lift pot and transport lines.

The air used for fluidizing the bed of uranium trioxide is compressed by a Nash Hytor compressor. This is sealed with water and fitted with separators to prevent carry over of entrained water into the drier used for drying the air before it enters the reactor. Air enters the base of the reactor through a series of nozzles the size of which has been calculated to give a gas velocity through each individual nozzle sufficient to prevent back-streaming of solid particles. The nozzles are so placed that the volume of air passing to each group of nozzles can be measured by means of an orifice plate and meter. The dried compressed air is first preheated by interchange of heat with the hot gases leaving the top of the reactor. It has been found that the most satisfactory method of controlling the gas distribution is by measuring the temperature inside the heater tubes. Blockage of fluidizing nozzles is immediately apparent by a fall in the temperature of the tube supplying the nozzle.

Very satisfactory operation has been obtained by using a bed temperature of 300°C, the trioxide produced being chemically suitable for the next stage of the process.

By using traversing thermocouples inside the heater tubes it was found that the state of fluidization in the base of the reactor was not stable; this is a characteristic of most fluidized beds. This instability caused considerable trouble during the commissioning of the reactor because

Fig. 1 Evaporator system for uranyl nitrate



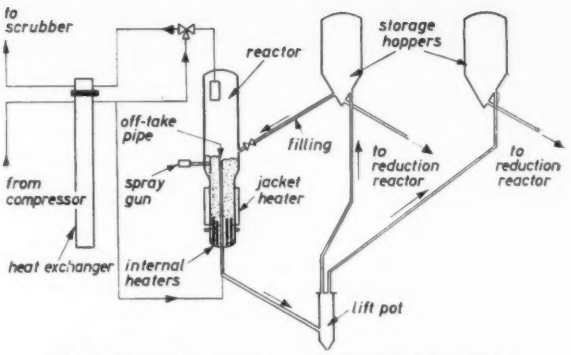


Fig. 2 Converting uranyl nitrate into uranium trioxide

heat was not satisfactorily removed from the heater tubes in this zone, which resulted in burning out of the heater elements. These difficulties were overcome by applying heat only to the elements outside this unstable zone.

To prevent loss of oxygen from the trioxide due to overheating, the reactor wall temperature is controlled at a maximum of 600°C. The flow of air to the reactor for fluidizing purposes and its pressure are controlled automatically by flow and pressure recorder controllers.

REDUCTION

The object of this process is to convert uranium trioxide into uranium dioxide. The reactor (Figure 3) is identical in shape with the denitrator but is smaller in diameter. The material of construction is again stainless steel and it is fitted with the same type of filters. The contents of the reactor are fluidized with hydrogen previously compressed by a Nash Hytor compressor sealed with 4% caustic soda solution. Due to the exothermicity of the reaction and the damage to the particles of dioxide that results from reactions carried out at too high a temperature, great care has to be taken in the control of the temperature and the addition of the uranium trioxide.

During the development work it was found that when a large batch of trioxide was reacted with hydrogen at 500°C the heat of the reaction was sufficient to cause damage to the particles of dioxide, resulting in a product which was unsatisfactory for hydrofluorination. To overcome this difficulty the trioxide was added in small increments so that at any given time the quantity of material reacting with hydrogen in the bed was small compared with the total mass of solids within the reactor. From experience gained during the commissioning of the full-scale plant, it became evident that the bed should be heated externally to the desired reaction temperature and the reaction allowed to proceed at that temperature either by addition or removal of heat rather than by raising the temperature of the bed initially by the heat of reaction. If the heat of reaction is used some of the particles of dioxide become permanently damaged. By using this technique at Springfields satisfactory uranium dioxide has been made in substantial quantities.

As with the denitrator, considerable thought has been applied to the question of heat conservation. The waste gases leaving the top of the reactor, consisting of steam and unreacted hydrogen, are passed through a multi-pass heat exchanger where they exchange their heat with the fluidizing gas entering the base of the reactor. The reactor

is heated from the outside by means of electrical heating elements contained in two removable jackets. The insides of these jackets are baffled so that cooling air can be directed across the heating elements when necessary.

The flow of hydrogen into the Nash compressor is indicated by a transmitting rotameter and controlled by an air-operated valve on the inlet side of the compressor. The compressor and reactor operate on a closed cycle: the excess hydrogen leaving the top of the reactor via the filters is fed back into the compressor. As hydrogen is consumed during the reaction the pressure on the inlet side of the compressor falls and the control valve opens and allows more hydrogen to enter the cycle. The end of the reaction is indicated when the transmitting rotameter no longer shows a flow of hydrogen. To confirm that the reaction is completed samples of the product are removed from the base of the reactor through a gas lock and analysed for hexavalent uranium. The level of solids within the reactor is determined by means of a nucleonic device operating on the gamma ray absorption principle.

The batch of uranium dioxide is removed from the reactor through a valve in the base and is transported in a stream of dry nitrogen into storage hoppers situated above the reactors.

Once the basic difficulties associated with poor gas distribution and heat transfer had been overcome, the operation of the denitrator and reduction reactor became routine and non-technical foremen and process workers are now able to operate these reactors with little difficulty. The poor gas distribution mentioned above was not experienced on the pilot plant, but throughout the commissioning period of the large-scale plant differences have been found which can only be associated with scale-up effects.

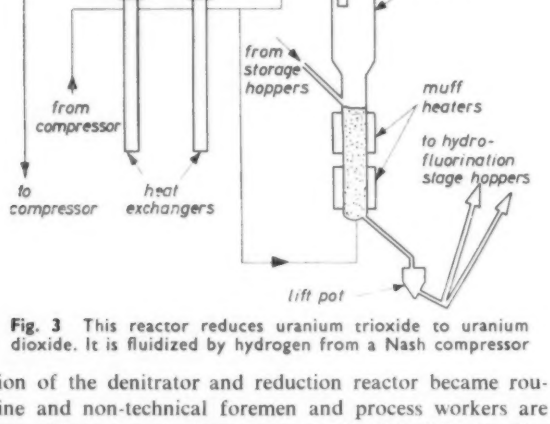


Fig. 3 This reactor reduces uranium trioxide to uranium dioxide. It is fluidized by hydrogen from a Nash compressor

HYDROFLUORINATION

This process converts uranium dioxide to uranium tetrafluoride. The hydrofluorination stage of the process and the associated hydrofluoric acid gas-generating and recovery plants have given considerably more trouble during their commissioning stages than the reactors described above. This is not surprising, however, in view of the properties of hydrofluoric acid, particularly in dilute concentrations.

The two reactors used for the hydrofluorination of uranium dioxide are made of inconel, an alloy which is particularly resistant to the corrosive attack of hydrofluoric acid even at elevated temperatures. The reactors are similar in shape to the reduction reactor but are somewhat longer. They are fitted with sintered metal filters as described above, in this case made of monel. All pipe lines carrying hydrofluoric acid to and from the reactors, the heat exchangers and condensers are also of monel.

One of the first important problems met was the method of valve construction. It was found that those made from castings were totally unsuitable as the acid very quickly removed the sand from the pores of the metal structure. Ones made from forgings have proved most satisfactory.

To withstand the attack of all concentrations of hydrofluoric acid at elevated temperatures a particularly high standard of monel welding was necessary. Wherever possible butt welds were used as they are amenable to radiography, whereas fillet welds are not. Weld neck flanges were also used wherever possible throughout the plant.

Trouble was initially experienced with the lens type joint rings used in the pipe joints. At first nickel rings were tried as this material is very resistant to hydrofluoric acid and is slightly softer than the monel flanges. It was thought that this would reduce deformation of the flanges to a minimum. However, severe corrosion of the rings took place because of the galvanic couple set up between the ring and the flange. The nickel rings were replaced by monel rings which have given complete satisfaction. Spirally-wound monel-fluon spiretz rings have also been found very suitable for this duty, particularly where grooved flanges have been damaged at the groove face, making the use of a lens ring impossible. The gases used for fluidizing the beds in the hydrofluorination reactors are nitrogen and hydrogen fluoride gas.

The hydrogen fluoride is received at the works as liquid anhydrous hydrogen fluoride and is transferred to large mild steel stock tanks from the rail tankers by means of compressed air. The liquid is then transferred to smaller tanks and pumped to the boilers by diaphragm pumps totally submerged in the acid. The level in the boilers is maintained by level controllers which operate valves situated on the delivery side of the pumps. In the case of the anhydrous hydrofluoric acid boiler the acid is vaporized by heat supplied from steam which passes into and condenses in horizontal tubes situated inside the boiler shell. In the dilute hydrofluoric acid boiler the heat is supplied by electricity because of the higher boiling point of the dilute acid. The electrical elements are inserted into horizontal monel tubes which are themselves expanded and welded into a tube plate. The vapour from each boiler then passes through electrically heated superheaters which ensure that the acid is in the completely dissociated state necessary for accurate measurement of flow. This measurement is made by a transmitting rotameter which in turn operates a flow control valve. The gas passes finally through a heat exchanger where it is further heated by the exit gases leaving the top of the reactor. During the early stages of the reaction this heat exchanger is by-passed.

While the reactor is being filled with uranium dioxide the bed is fluidized with nitrogen. The reactor is then heated by electrical elements similar to those described under the reduction process. Hydrogen fluoride is introduced with the nitrogen which is correspondingly reduced. The dilution of the hydrofluoric acid with nitrogen is necessary to avoid too great a rise in temperature which would result in either de-activation of the dioxide or sintering of the tetrafluoride. Furthermore, owing to the fact that two molecules of steam are formed from four

molecules of hydrogen fluoride supplied, a decrease in the volume of fluidizing gas passing through the bed results, and must be compensated. The starting temperature has to be such that no condensation occurs with the higher boiling concentrations of acid but not too high to initiate a vigorous reaction, resulting in thermal damage of the dioxide.

During the early stages of the reaction the cooling fans are used and the concentrations of hydrogen fluoride in the condensed gases leaving the reactor indicate the way in which the reaction is proceeding. From an economic standpoint, it is important, during the early stages of the reaction, to remove as much of the stoichiometric water from the reaction with the loss of as little unreacted hydrogen fluoride as possible. When the velocity of the reaction reduces to the point when the bed temperature begins to fall, the fans are turned off and the bed temperature slowly increased to the final operating temperature. The reaction is finished by increasing the concentration of hydrogen fluoride in the reacting gas until the anhydrous hydrogen fluoride concentration is reached. When the concentration of hydrogen fluoride in the condensate becomes equal to that in the gas entering the reactor, a sample of that reaction mixture is taken for analysis to confirm that the reaction is complete. Before the product is removed into drums it is purged of residual hydrogen fluoride by means of nitrogen.

The tetrafluoride is removed from the bottom of the reactor through a poppet valve and piped to a cyclone fitted with cotton filter bags. The cyclone is evacuated by a turbo-blower which finally discharges the air to atmosphere through an *Absolute* filter. A star valve and a mucon valve fitted into the base of the cyclone finally control the flow of tetrafluoride into drums.

To ensure that the poppet valves in the reactor will not give trouble during the subsequent batches, they are removed for servicing after each run is completed. By paying strict attention to maintenance of the mechanical equipment which comes into direct contact with the hydrofluoric acid, little trouble has been experienced during the offloading and sampling operations.

The hydrofluoric acid generating and recovery plants have been built outside the main building and are uncovered.

The exhaust gases from the reactors pass into brine-cooled condensers which are finally vented to a scrubber containing dilute caustic soda solution. The condensate leaving the condensers can then be directed in any one of three ways, depending on its concentration. If sufficiently dilute, it is neutralized with caustic soda and discharged to drain. If its concentration is greater than 98%, as is the case at the end of the reaction, it is transferred to the anhydrous hydrofluoric acid storage tank. If the concentration lies between these two extremes, it is transferred to a dilute hydrofluoric acid stock tank where it is held until it can be distilled.

A constant supply of nitrogen must always be available to maintain the fluidization of the bed should the hydrogen fluoride gas supply fail, otherwise sintering of the tetrafluoride will take place.

NITROGEN SUPPLY

Liquid nitrogen is stored in containers from which it can be vaporized. After reducing its pressure to 50 lb/in²g, the gas is fed to the inlet side of a Nash compressor. The nitrogen used with the hydrogen fluoride during the hydrofluorination reaction finally leaves the condensers and enters the base of the scrubber. Here the traces of any condensed hydrogen fluoride are removed with caustic soda solution and the nitrogen leaving the top of the scrubber is then piped back to the inlet side of the Nash compressor. The nitrogen system is therefore a closed cycle and fresh nitrogen only enters the cycle when the inlet pressure of the Nash compressor falls below a predetermined value of about 1 lb/in²g. This is controlled by a pressure recorder controller which operates a valve allowing nitrogen to enter the cycle. The delivery pressure is kept constant by a similar device which allows nitrogen to pass back to the inlet side of the compressor if the pressure rises above a certain predetermined figure.

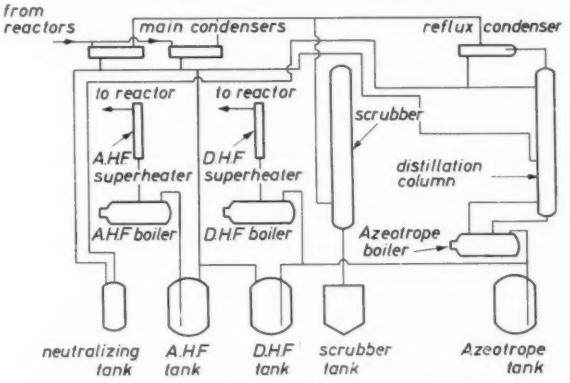


Fig. 4 Flow diagram of the hydrofluoric acid recovery plant

HYDROFLUORIC ACID RECOVERY

To achieve maximum economy in the use of hydrofluoric acid it is necessary to recover the acid not used in the process. At Springfields this is done by distillation (Figure 4). Hydrofluoric acid and water together produce an azeotropic boiling mixture consisting of approximately 38% hydrogen fluoride. If, therefore, mixtures containing more than the azeotropic concentration of hydrogen fluoride are fed to a distillation column, the top product will eventually be 100% hydrofluoric acid and the bottom product the azeotropic mixture. If concentrations less than the azeotropic concentrations in hydrogen fluoride are used as feed to the column, and the latter is suitably designed, the top product will be water and bottom product the azeotropic mixture. The distillation column in use at Springfields, which contains sieve plates made of monel, is itself constructed from this alloy. It has been designed to give sufficient flexibility in operation to deal with any concentration as feed above or below the azeotropic composition.

The column is equipped with a steam heated boiler, a reflux condenser and a scrubber operating at atmospheric pressure. The feed is controlled by means of a control valve and the boil-up rate is controlled by the flow of steam to the boiler. The composition of the top product is controlled automatically by means of acid refluxing from the condenser. This flow is maintained by an air operated valve controlled by the temperature recorder controller on the top of the column. The level in the column re-boiler is maintained by a gamma-ray level recorder controller, so that moving parts of the instrument do not come into direct contact with the acid.

Cross Section by GRACCHUS

ONCE AGAIN the United States Atomic Energy Commission has come out with its financial report in which it shows by dozens of tables and graphs just how it has spent billions and billions of the US tax-payers' money. At the same time, gaps are cunningly left in it so that you and I cannot even make an estimate of just how many 'top secret' items have been produced. In doing this there must naturally be a borderline, and coming into this category is a subject which has intrigued me for years—nuclear propulsion for aircraft. Despite the world-wide shrinkage of the aircraft industry, the AEC is still appropriating vast sums for this project and, as far as I can calculate, nearly 400 million dollars have been obtained since 1950 for research and development. The outcome of this, as far as I can glean from released information, is that several good experimental facilities have been built, while at various times the US Air Force and Navy have both denied any need for a nuclear-propelled aircraft. They have even gone further and said that they have not got a suitable airframe into which a nuclear propulsion unit could be installed.

THE BRITISH love of local committees is well known and already the nuclear power stations under construction have provided good excuses for bigger and better committees. In several sections of the Scottish press I have read that a committee has been set up to protect the inhabitants around Hunterston; it is similar in composition to those already formed for Bradwell and Berkeley. At its inaugural meeting, it consisted of a chief constable, medical officers, county clerks, members from two county councils, representatives of the Civil Defence, Milk Marketing Board, the Department of Agriculture, Regional Hospital Board and, yet to be appointed, representatives from the National Farmers' Union. As there is no indication of any representation from either the United Kingdom Atomic Energy Authority, or the South of Scotland Electricity Board (who will operate the station), this committee appears to be suitable for organizing anything from a garden fete to protecting the county in the event of an invasion from outer space, but not an accident at Hunterston. So as to prevent any misunderstanding by those of us south of the border into thinking this is an independent government for Scotland, *The Guardian* reports that 'the area of the committee's "jurisdiction" extends up to ten miles from the station'.

At Chapelcross a rather similar situation exists except for the fact that the AEA here has kept an ace up its sleeve. Recently a perfectly normal company wished to establish a new factory in the vicinity. Permission was refused by the local county council on the recommendation of the Authority. Why? No reason given. This is interesting because the factory was to be well outside the 'fence'. Are the authorities still not quite sure whether they have thrown their net far enough or not? Rumour has it that the AEA is now considering approaching the local authorities to purchase the land in question themselves. Is this for a secondary protection area?

HEARING THAT NUCLEAR POWER was running a short article on DR3 this week (p 130), a friend of mine asked if he might contribute a few comments. I agreed and here they are:
'On July 23, 1957, I stepped off an aeroplane at Kastrup Airport looking for companies who would like to receive contracts for building bits and pieces for the DR3 reactor. In a matter of weeks I had visited several dozen works in various parts of Denmark all of which were anxious to participate and all of which had not had any previous experience in fabricating reactor components. Even the very extensive British paperwork and drawing requirements did not deter them and they laughed at "clean conditions". "Look at our foundries and heavy fabricating shops; aren't they clean enough for you?" they asked. Quite honestly I had to agree. In fact I saw many metal-working shops that were cleaner than quite a number of hospitals in the UK. Within a few months most of the contracts for this Anglo-Danish project had been placed and work was getting under way. From the majority of UK companies participating, a stream of requests went to the Danish Atomic Energy Commission asking either to increase the price, or to delay the deliveries. On the other hand, the majority of Danish firms kept to their original prices and deliveries. What is this leading up to? Since those early days, I have worked for a Danish group and while I was living in Copenhagen I was frequently told that after Burmeister & Wain had started a nuclear division, it would only be a matter of time before they were building marine nuclear installations which would be as efficient and as widely used as their large marine diesel engines—now made under licence in pretty well every maritime country in the world. I was therefore not surprised when I attended the international marine nuclear conference at Hamburg last year, to find many representatives from Danish shipping concerns; I *was* surprised to note that British shipbuilders and owners were conspicuous by their absence. Will we hear an announcement in the not too distant future that Danish industry has got into the marine field before the United Kingdom?'

UNWITTINGLY the House of Lords has hit on a solution to a problem which will doubtless arise when nuclear propelled merchant vessels become popular. At present ships that have served a full and useful life with one of the more respectable mercantile navies are usually sold, not as scrap, but to an owner in one of 'the flag of convenience' countries. Will the same thing happen with nuclear ships, and if so how will it affect safety and life of the reactors concerned? Lord Teynham has suggested that the Government should encourage the scrapping of old ships and proposes that a useful life should be defined as twenty years. This period of operation would fit in very nicely with current estimates for the life of power producing reactors. His lordship went further and said that this proposal should be introduced at the international conference on safety at sea, to be held in Britain in May. As already nuclear propulsion is on the agenda at this conference, why not establish this term of life on an international basis and save possible danger and trouble in the future?

AT a recent meeting of the Institute of Welding, Mr. Prince of the Motherwell Bridge & Engineering Company said 'among the problems facing reactor vessel fabricators was the need for a more detailed knowledge of radiation effects on materials and a determination of safe operating temperatures as far as material properties were were concerned.' He criticized BS1500 and said 'this code will have to be extended to cover all the different requirements that are forced on the fabricator of a reactor.' After this is done I hope the Hunterston troubles will not be repeated.

Reactors

A study of uranium hexafluoride fuelled reactor using sodium cooling

A gaseous-fuel fast breeder reactor

by FREDERICK G. HAMMITT, Associate Professor, Nuclear Engineering, University of Michigan

A GASEOUS-FUELLED research reactor using UF_6 is in operation in Russia (*1*). Two schemes for UF_6 gaseous-fuelled power reactors have been advanced recently (*2, 3*) and the possibility of a reactor, where the core is the internal volume of a cylinder-piston combination, becoming critical for those portions of the stroke where the clearance volume is suitably reduced, has been examined.

Of the possible gaseous fuels, uranium hexafluoride is an obvious first choice. Its critical pressure and temperature are sufficiently low to allow operation in the supercritical range (482°F and 675 lb/in² abs (*2*)). According to a previous article (*2*) it is anticipated that decomposition of the UF_6 in a radiation field can be held to suitable limits by the addition of strong fluorinating agents such as BrF. It is also stated (*2*) that aluminium and nickel and their alloys are probably compatible container materials at temperatures up to 1100°F.

The proposed reactor is a sodium-cooled fast breeder power reactor somewhat similar in size and output to the APDA Fermi Reactor (*4*).

To obtain a sufficient quantity of fissionable material within the small core using gaseous UF_6 fuel, it is necessary for the pressure to be extremely high. In view of the high temperatures which are necessary to attain suitable heat engine thermal efficiency, and also because of the large internal gradients corresponding to suitably high heat fluxes, the UF_6 will be supercritical throughout. Hence no phase changes will be involved.

The only apparent way to attain these objectives is that the UF_6 be contained within a multiplicity of small bore ligaments of a material compatible with both UF_6 and sodium, and capable of withstanding the required pressure and thermal stresses at the operating temperature (Figure 1 is a schematic representation). These ligaments could be individually valved-off so that no high-pressure headers would be required and it would be possible to empty and recharge an individual ligament at will. Alternatively, they could be connected into small common headers (see figure) in which case a continuous small-flow reprocessing stream could be used.

Engineering design

A first order feasibility evaluation of this conceptual design was made under the writer's supervision as a student project in the nuclear engineering programme at the University of Michigan (*5*).

The capability of the presumed plant was patterned after that of the APDA Fermi reactor as the tabulated numerical data shows. Since this was only an approximate feasibility study, no nuclear criticality calculations were made. However, to reduce somewhat the required UF_6 pressure, the core volume was increased over the APDA design and as a result some credit taken for a reduction in fissionable material loading. The sodium flow-rate and temperatures, and the reactor heat output, are unchanged.

It is assumed that the UF_6 is contained within 1/16 in. o.d. ligaments of 0·005-in. wall thickness, spaced with a triangular pitch of 0·0725 in. If it is further assumed that the perfect gas laws can be used as a first approximation as the equation of state for the UF_6, it is found that the required amount of fissionable material can be contained in the core if the UF_6 pressure is 5630 lb/in² abs and the mean temperature for a ligament along the core centre-line is 2575°F. A 'clipped cosine' flux and heat generation distribution, falling to $\frac{2}{3}$ of the maximum in both radial and axial directions, was assumed. The mean temperature estimates correspond to a maximum ligament centre-line temperature of 3340°F. The internal ligament heat transfer estimates are based on the results of a previous internal heat source, closed-cell natural convection study (*6*) by the writer. Considering the heat source strength, ligament dimensions, and estimated fluid properties, it appeared that the contribution of natural convection in reducing the internal temperature differentials would probably be slight and the internal circulation laminar. Consequently, the calculation was based on static conduction. It is quite likely that this result is over pessimistic both because of the effect of natural convection and, in view of the high temperature, also of radiation. In any case the ligament temperature is close to that of the sodium because of the high coefficient on the sodium side and the extremely small wall thickness of the ligament. Temperature differential across the wall is a maximum of about 60°F and that across the film less than 1°F.

In view of all the foregoing, a suitable ligament material might be Inconel X. As a nickel alloy it appears likely to

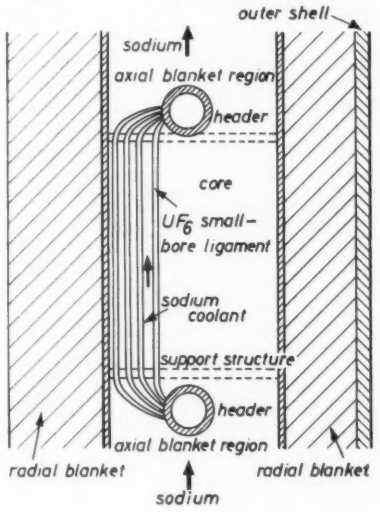


Fig. 1 Schematic diagram of the UF_6 gaseous-fuelled fast reactor concept

be compatible with UF_6 at the contract temperature (about 900°F maximum (*2*)) and is compatible with sodium (*7*). At 1000°F it shows a 1000-h creep strength of 68,000 lb/in², considerably better than possible competitors. It is not an excessively difficult material to fabricate and, having a moderate neutron absorption cross-section, is not incompatible with the requirements of a fast reactor. The maximum hoop stress to which the ligaments would be subjected is 28,600 lb/in². Hence there is a safety factor of about 2·4 based on the 1000-h creep stress to offset thermal stresses and possible bending stresses. As a first approximation, the design seems reasonably feasible from the stress viewpoint.

TABLE I *Reactor characteristics compared with APDA*

	APDA REACTOR (*4*)	UF_6 REACTOR
Reactor output, MWh	300	300
Fissionable material loading, kg	485, U-235	250, U-235 (assumed)
Core diameter, in.	30·5	40
Core height, in.	30·5	40
Sodium flow rate, lb/h	$1{\cdot}32 \times 10^7$	$1{\cdot}32 \times 10^7$
Sodium inlet temp., °F	550	550
Sodium mixed mean outlet temp., °F	800	800
Sodium mean velocity, ft/s	32·5	24·3

Conclusions

It is concluded that a UF_6 gaseous-fuelled, sodium-cooled fast power breeder reactor is not beyond the bounds of possibility. The major difficulty apparent from this study is the mechanical complexity involved in a very large number of small-bore tubes which must be either individually valved-off or connected into a high-pressure header. Aside from this, the major problems are probably those of material compatibility under conditions of high temperature, stress, and radioactive flux. However, the potential advantages from such a system in terms of low initial fuel costs and ease of reprocessing are large.

Acknowledgments

The basic concepts of the hypothetical design grew from conversations between the writer and Mr David Aronson of the Worthington Corporation. The detailed calculations on which the conclusions were based are the work of Mr Alexander H. Haynes.

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Materials

Permissible values of control parameters and some potential fault conditions are investigated

Organic-moderated marine reactor transients

by G. M. BRACEWELL, A.M.I.E.E., B.J.R., Atomic Power Constructions Ltd.

IT HAS been pointed out (*1*) that the first marine reactors will probably operate under an economic penalty imposed by the need to provide elaborate means of control and instrumentation until the precise operating characteristics of the reactors have been determined. This is particularly true of liquid-moderated and cooled reactors, designed to operate under nominally non-boiling conditions, since many of the factors affecting the safety assessment require prior data on the reactor response during transient boiling conditions and this, paradoxically, can generally be obtained only by constructing a prototype.

The amount of such data generally available on organic liquid heat transfer (*see 2*) in actual OMR systems is quite limited and this must be taken into account when assessing the feasibility of the reactor for a given application, since both the safety and the operational availability are directly involved. From a safety viewpoint it must be assumed that an area of uncertainty in the reactor response occurs during transients involving the several modes of boiling. This results in 'pessimistic' restrictions on the rate and magnitude of control variables, which in turn will affect the availability of power.

REACTOR DETAILS

The reactor under consideration, basically similar to that described in (*3*), has an output of about 170 MWt. The organic coolant flows through fuel element bundles which are separated from the (lower velocity) organic moderator, by stainless steel sheaths. Bulk coolant inlet temperature is 295°C, with normal outlet temperature 331°C. It is assumed that 34 control elements are available, having a total worth of 7·2%, together with 2% worth of safety elements. The net available built-in reactivity is 6·2% at the organic liquid trace heat temperature. The temperature coefficients relate to a moderator/fuel ratio of 2·0 and conversion factor 0·72.

The normal maximum can temperature is 410°C (centre channel maximum) and the related peak fuel (assumed UO_2) temperature is in the range 900–1400°C. Preferential can temperature distribution is obtained by gagging appropriate channels. Centre channel flow velocity is about 20 ft/s. It is assumed that power control will be effected by changes to both coolant flow and control elements, to achieve fairly constant temperatures over the load range. Flow changes are initiated at servo-operated throttle valves, and a coupled by-pass system is provided to avoid overcooling when the plant is operating at part loads. The reactor is intended for ship propulsion, and it is assumed that the start-up time following a controlled shut-down to stand-by conditions should be of the order of a half-hour. About double this time might be required following an emergency shut-down.

DISCUSSION

The validity of the mathematical treatment ends, with the onset of gross (sub-cooled) nucleate boiling, for lack of a reliable heat transfer (transient) correlation for the successive stages of boiling applicable to organic liquid cooling. Since the heat transfer will tend to improve when forced convection heat transfer changes to sub-cooled nucleate boiling, the initial effect might probably be a reduction in the rate of attenuation of a given power

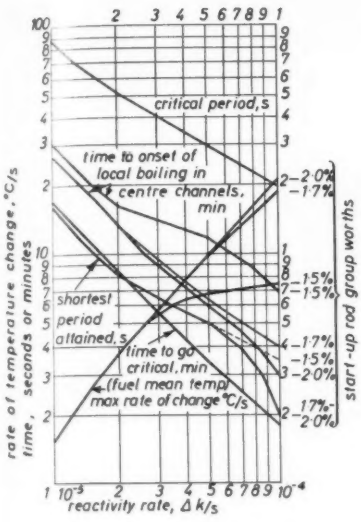

Fig. 1 Rate of change of temperature with reactivity rate for unrestricted withdrawal of control rods at start-up; positive moderator coefficient

surge. The overall effect, however, as the heat transfer approaches film boiling should result in a very rapid attentuation of power. The important question is whether or not a given power surge will attenuate such that burn-out heat flux levels are avoided.

Experimental correlations of these effects tend to be valid only for the given experiment, thus an area of uncertainty frequently remains which must be taken into account until the reactor characteristics have been properly determined. It is assumed that an area of uncertainty appears with the onset of nucleate boiling and that, for safety purposes, this must be regarded as the beginning of a possibly dangerous condition of the reactor.

A further general question arises of whether the fault conditions should be evaluated in the light of possible coincident trip failure. In selecting control rates in the light of their effect under fault conditions, one can clearly obtain maximum operational availability by assuming that the safety trips are stable and not subject to failure, or by assuming that a given servo-system can handle large reactivity control investments over a wide frequency range without any possibility of malfunctioning or failure. At the other extreme one might place restrictions on the control variables and trips such as to make the reactor almost inoperable. The philosophy here used is to attempt to organize the rate of approach to dangerous conditions so that in the event of a fault or maloperation accompanied by trip failure, a reasonable amount of time is available in which to take direct action before a serious situation can develop.

Reactivity rates and rod group worth

It is desirable that any rod or rod group be able to have its duties interchanged with other units without physical alteration. Flux distribution changes and burnup may require arbitrary assignation of groups to safety, start-up, or regulating duty. Interchangeable drive units also have obvious maintenance advantages. The drive units should have an absolute maximum velocity limit but with a range of velocities below this limit. Similarly the drive should fail to safety under any fault condition. The absolute maximum velocity limit (in terms of positive reactivity increase per second) should refer to all those rod groups which are capable of simultaneous movement under any credible fault condition. It may be necessary to manoeuvre the main rod groups in small discontinuously operated sub-groups to correct any space-time changes in the flux distribution as the reactor diverges. For present purposes, however, the reactivity rates under consideration are the mean value for the group.

Figure 1 shows various parameters plotted against reactivity rate for a few values of start-up rod group worth. The initial sub-criticality is taken as -1%. The reactivity rate is applied continuously until either the rod group worth is released or the problem terminates with the onset of nucleate boiling. Operational availability can be gained either by reducing the time available in which to take action against a reactivity fault occurring at low-flux level (or when the reactor is nominally shut down), or by drastically curtailing the rod-worth capable of movement at these flux levels, provided the rate of change of fuel element temperature does not exceed that which is permissible. Figure 2 shows that irrespective of reactivity rate, the reactor will not boil as a result of this fault condition, provided the rod group (or sub-group) worth capable of movement is less than about 1·43% reactivity.

Selection of an upper limit for the reactivity rate, however, still requires a knowledge of how the fuel element will react to rapid changes in temperature and this is likely to present a further area of uncertainty. Alternatively, if a rate is selected to give a normal operational (total) start-up time from -1% sub-criticality of about 30 min (the reactivity rate being about $10^{-5}\ \triangle k/s$), the rate of change of fuel element temperatures in the event of unrestricted rod group withdrawal would be on the order of a few degrees centigrade per second and the element should be designed to remain integral during these short duration, very infrequent, transient temperature stresses. If this reactivity rate is applied under fault conditions when the reactor is near operating temperatures, the rate of temperature change is about 18°C/min (see Figure 2). Boiling will not occur provided the regulating rod group worth is less than $+0{\cdot}4\%$ about its operating centre. A similar fault occurring when the reactor is at hot-standby (see Figure 3) will cause boiling within 2 min of the fault onset.

Selection of permissible reactivity rates (hence determining the operational availability) on a *logical basis* is not feasible without prior data on fuel element transient temperature stresses. Selection of a safe maximum for rod group reactivity worths requires prior data on transient (boiling) heat transfer in the core. If sufficient reliable data is not available considerable sub-division of the control rods will be necessary together with a positively interlocked

Fig. 2 The onset of local boiling is independent of reactivity rate (left); temperature increases with unrestricted regulating group withdrawal (right)

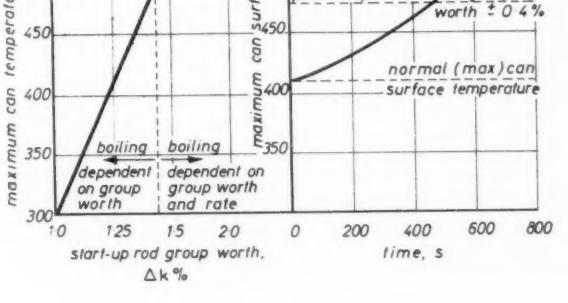
onset of local boiling independent of reactivity rate
maximum can temperature, °C
boiling dependent on group worth
boiling dependent on group worth and rate
start-up rod group worth, Δk%
maximum can surface temp., °C
onset of sub-cooled nucleate boiling
peak temperature for group worth + 0·4%
normal (max) can surface temperature
time, s

TABLE 1 *Some specific transients*

INITIAL CONDITIONS	DIVERGENCE AT LOW FLUX LEVELS	DIVERGENCE IN LOW POWER RANGE (HOT STANDBY CONDITION)	DIVERGENCE AT FULL LOAD	LOSS OF COOLANT FLOW
Power level	10^{-5} f.l.	1% f.l.	100% f.l.	100% f.l.
Coolant flow	15% f.l. (constant)	15% f.l. (constant)	100% f.l. (constant)	100% f.l. initial)
Inlet temp., °C	295 (controlled constant bypass)	295 (controlled constant)	295 (constant)	295
Core mean temp., °C	295 (by external injection)	296	—	—
Positive reactivity rates, $\triangle k/s$	10^{-5}–10^{-4} (limits 1·5%, 1·7%, 2%)	10^{-5}	10^{-5}	—
Bulk outlet temp., °C	—	—	331	331
Notes	*see* figs. 1 and 2	*see* fig. 3	*see* fig. 2	*see* fig. 4

programme of rod movements during operation and some mechanical and electrical complications may be expected.

Coolant flow

The data in Figure 4 were obtained by varying the coolant flow at different rates and observing the natural response of the equations.

Two conditions are of interest, namely, sudden catastrophic loss of coolant flow, and gradual loss due, say, to power failure to one or more of the four pumps. The former might be due to a breach in the primary circuit. In a marine application such a breach would be followed

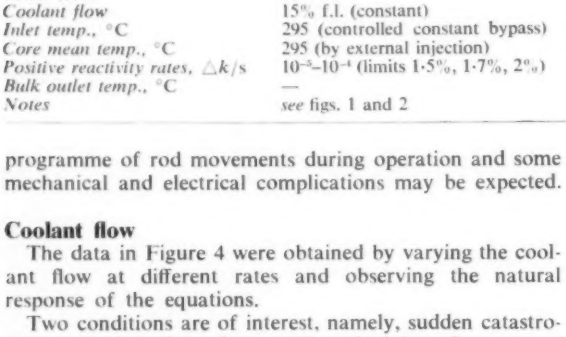

Fig. 3 Unrestricted withdrawal of rod group with reactor at hot stand-by: initial power level 1% f.l.; cooling flow 15% f.l. (constant); reactivity rate $10^{-5} \triangle k/s$ (positive moderator coefficient)

by a closure of fast acting valves at the reactor inlet and outlet, therefore spurious closure of these valves could also result in similar loss of flow The shortest credible time for such loss is estimated to be about 5 s. If no action to reduce power is taken, other than by temperature coefficient effects, the reactor will begin to boil within 3 s of the onset of the fault. Further computations show that the emergency shut-down devices must insert negative reactivity rate of about -1 %/s, within 1 s of this fault occurrence, if boiling is to be avoided. This seems generally to indicate that fast emergency devices will be required if sudden breach of the primary circuit is a credible accident in the given reactor application.

The other fault condition, i.e. power failure to one or more of the four pumps, can be handled without emergency measures provided the coolant flow reduces at a rate below about 0·2 ft/s².

CONCLUSIONS

The preliminary investigation has clearly shown the extent to which the safety and feasible performance of the reactor (and, therefore, implicitly the steady state design points) depends on having available experimental data regarding transient (boiling) heat transfer, burn-out data, and fuel element integrity so that the transient performance may be properly assessed.

A few basic observations are in order, however, since the feasibility study has been strictly confined to those operating regions within which the mathematical treatment and coefficients have reasonable validity.

a. Clearly, adequate operational availability for the intended application can be had with this reactor design, without any major safety complications intruding at start-up, provided the elements could withstand a few degrees C per second rate of rise in emergency conditions.

Provided the maximum positive reactivity rate is kept below about $2 \times 10^{-5} \triangle k/s$ there appears to be little advantage to be gained by arranging the initial start-up rod movements in groups worth below the range about 1·5–2% for the intended application.

If for other applications faster start-up rates are required, considerable limitation of rod worths and movements, or fast tripping circuits will be required, depending on how the transient (boiling) heat transfer and burn-out data turns out. (The prototype would probably require both features.) For such applications, it might be worthwhile to reassess the design with a view to obtaining more suitable temperature coefficients, and associated time lags.

Rod group worth of not more than about ½% is clearly indicated for on load power regulation duties.

b. Sudden loss of coolant flow will cause this reactor to boil within very few seconds of the fault onset. If experimental data indicates that rapid attenuation of heat transfer surface temperatures is necessary then the choice must be made whether to develop fast moving, guaranteed, shut-down mechanisms and core isolating valves or to improve the inherent self-regulation at the expense of some other design objective.

c. The need for data on which to base predictions about the heat transfer (and other properties) of fuel elements in organic liquid when the heat transfer mode is rapidly changing, raises a serious limitation in the formulation of a consistent safety policy for OMR and the need for adequate pilot experiments is stressed.

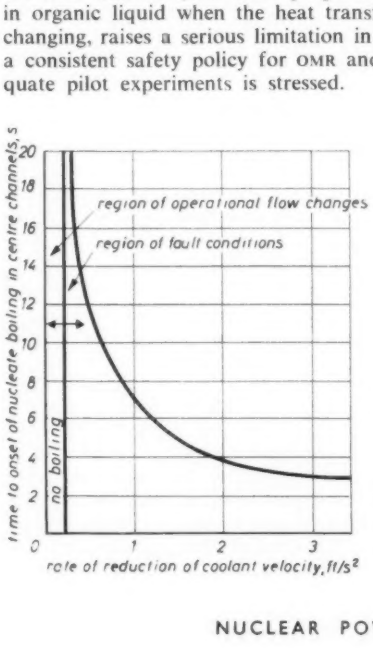

Fig. 4 Time to onset of boiling for various rates of reduction in coolant velocity, referred to centre channels. Regulation is by temperature coefficients only (positive moderator coefficient)

MATHEMATICAL REPRESENTATION

Representative channels

To investigate the transient behaviour of a (gagged) heterogeneous reactor using a limited number of computing elements, it is necessary to select a fuel channel which is representative of the whole reactor. It was found that the total core reactivity changes due to variations in power were similar to those of channels at about a half radius from the centre (called the ' most effective channels ').

The power (from kinetic equations), coolant flow, and inlet temperature relevant to this channel were inserted into the heat transfer equations, the fuel, coolant, and moderator temperatures produced being used to give the three thermal reactivity feedback quantities. The temperature coefficients used were those corresponding with two stages of burnup, i.e. zero and 10,000 MWd/tonne. The rated bulk outlet temperature is 331 °C under steady conditions, but the representative channel outlet temperature is 339°C and this forms the starting point for analogue computer calculations.

Heat transfer equations

The equations refer to a representative fuel channel. Input parameters to this channel are reactor power (from the neutron-kinetics equations), coolant flow, moderator flow, and inlet temperature. Output quantities produced are coolant and moderator outlet temperatures and the mean fuel temperature in the channel.

The following are definitions of the representative channel equation coefficients except where stated otherwise:

A	thermal capacity associated with fuel and can	Ws/°C
F	thermal capacity associated with coolant, can and tube	Ws/°C
M	thermal capacity associated with moderator and tube	Ws/°C
B	thermal conductance of fuel/can interface	W/°C
D	thermal conductance across can	W/°C
E	thermal conductance of can/coolant interface $= (38{\cdot}5)\,(V_c)^{0{\cdot}85}$	W/°C
H	thermal conductance of coolant/tube interface $= (13{\cdot}5)\,(V_c)^{0{\cdot}85}$	W/°C
K	thermal conductance across tube	W/°C
L	thermal conductance of tube/moderator interface $= (13{\cdot}7)\,(V_M)^{0{\cdot}33} + (0{\cdot}06)\,(V_M)^3$	W/°C
C	representative power generated in fuel	W
I	representative power generated in coolant	W
N	representative power generated in moderator	W
J	(thermal capacity) × (velocity) of coolant	Wcm/°C
P	(thermal capacity) × (velocity) of moderator	Wcm/°C
R	factor required in relating bulk and surface U temps	°C/W
S	factor required in relating bulk to maximum U temp in centre channel	°C/W
V_c	coolant velocity	cm/s
V_M	moderator velocity	cm/s
T_i	reactor inlet temp	°C
T_{co}	channel coolant outlet temp	°C
T_{MO}	channel moderator outlet temp	°C
T_F	channel bulk fuel temp	°C

In the model the total amount of fuel in one fuel bundle was considered as collected into a single fuel rod, in contact with the correct associated quantities of can, coolant, tube, and moderator. Using the true values of resistance to heat across the various zones and interfaces the following heat balance equations were derived:

$$A\frac{d\overline{T}_F}{dt} - C\left[1+\frac{R}{U_1}\right] + \left[\frac{1}{U_1}\right]\left[T_F - \frac{T_i}{2} - \frac{T_{co}}{2}\right] = 0$$

$$\frac{F}{2}\left[\frac{dT_i}{dt}+\frac{dT_{co}}{dt}\right]+\frac{1}{U_1}\left[\frac{T_i}{2}+\frac{T_{co}}{2}-\overline{T}_F+RC\right]$$

$$-\frac{1}{U_2}\left[\frac{T_{MO}}{2}-\frac{T_{co}}{2}\right]-I+\frac{J}{198}\left[T_{co}-T_i\right]=0$$

$$\frac{M}{2}\left[\frac{dT_i}{dt}+\frac{dT_{MO}}{dt}\right]+\frac{1}{U_2}\left[\frac{T_{MO}}{2}-\frac{T_{co}}{2}\right]-N+\frac{P}{198}\left[T_{MO}-T_i\right]=0$$

where $U_1 = \frac{1}{B}+\frac{1}{D}+\frac{1}{E}$, and $U_2 = \frac{1}{H}+\frac{1}{K}+\frac{1}{L}$

The following equations relating other core temperatures with those of the representative channel have been derived:

Bulk coolant outlet temperature $= T_i + 0{\cdot}82\,(T_{co} - T_i)$

Maximum coolant outlet temperature $= T_{co}$ and occurs at 0·775 of the maximum radius from the core centre.

Moderator + coolant bulk outlet temperature

$$= T_i + 0{\cdot}82/(J+P)\quad\{J(T_{co}-T_i)+P(T_{MO}-T_i)\}$$

Moderator + coolant maximum outlet temperature

$$= T_i + 1/(J+P)\qquad\{J(T_{co}-T_i)+P(T_{MO}-T_i)\}$$

and occurs at 0·775 of the maximum radius from the core centre.

Maximum can temperature

$$= T_i + 0{\cdot}459\,(T_{co}-T_i) +$$

$$\sqrt{0{\cdot}212(T_{co}-T_i)^2 + \frac{(T_F - T_i/2 - T_{co}/2)^2(1/E)^2}{(0{\cdot}722)^2(U_1+R)^2}}$$

and applies in all channels from the centre to 0·775 of the maximum radius from the centre.

Maximum uranium temperature

$$= T_i + 0{\cdot}440\,(T_{co}-T_i) +$$

$$\sqrt{0{\cdot}194\,(T_{co}-T_i)^2 + \frac{(T_F - T_i/2 - T_{co}/2)^2}{(0{\cdot}722)^2}\left\{\frac{1{\cdot}013}{E}+1{\cdot}37\left\{\frac{1}{B}+\frac{1}{D}+S\right\}\right\}^2}{U_1+R}$$

and occurs in the centre channel.

Equation coefficients and assumptions

The following coefficients were used in the neutron kinetic equations:

$l^* = 6\times10^{-5}$ seconds

$\beta_1 = 0{\cdot}000255,\quad \beta_2 = 0{\cdot}00086,\quad \beta_3 = 0{\cdot}002465,\quad \beta_4 = 0{\cdot}002176,$
$\beta_5 = 0{\cdot}00170,\quad \beta_6 = 0{\cdot}00026$

$\lambda_1 = 14{\cdot}3,\quad \lambda_2 = 1{\cdot}61,\quad \lambda_3 = 0{\cdot}456,\quad \lambda_4 = 0{\cdot}151,$
$\lambda_5 = 0{\cdot}0315,\quad \lambda_6 = 0{\cdot}0124$

The assumptions made are:

a. Separability of time space variables.

b. The multiplication factor k is normally fairly close to unity and that reactor power is proportional to neutron density.

c. The following two sets of reactivity temperature coefficients (referred to the appropriate reactor zone) were used:

$MWd/tonne$	$\partial k/\partial\overline{T}_M$	$\partial k/\partial\overline{T}_c$	$\partial k/\partial\overline{T}_F$
0	$-5{\cdot}3\times10^{-5}$	$-0{\cdot}5\times10^{-5}$	-4×10^{-5}
10,000	$+8\times10^{-5}$	0	-4×10^{-5}

where $\overline{T}_M$ = moderator mean temperature, °C

$\overline{T}_c$ = coolant mean temperature, °C

$\overline{T}_F$ = fuel mean temperature, °C

The thermal capacity of the ' cans ' and coolant ' tube ' in a fuel bundle are assumed capable of being split into two parts; each part is then considered as included in the respective adjacent zone. Temperatures of the zones are assumed to apply across these appropriate parts in conjunction with the true thermal resistance across zones and interfaces.

d. Each fuel bundle has a certain quantity of moderator associated with it.

e. Mean temperature of the coolant is given by $(T_{co}+T_i)/2$ i.e., there is no transport delay.

f. Similar to **e.** the mean temperature of the moderator is given by $(T_{MO}+T_i)/2$

g. The difference between the fuel bulk and surface temperature is given by a constant term multiplied by the power developed in the fuel.

h. The flux across a bundle is constant.

i. Coolant velocity is greater than 15% of its full flow value, thus remaining turbulent.

j. Temperature coefficients do not vary greatly with temperature.

k. $\frac{d}{dt}(T_i) \simeq 0$. However, if T_i is changed the transients are overestimated.

Acknowledgement:
The work described was conducted at Hawker Siddeley Nuclear Power Co. Ltd.

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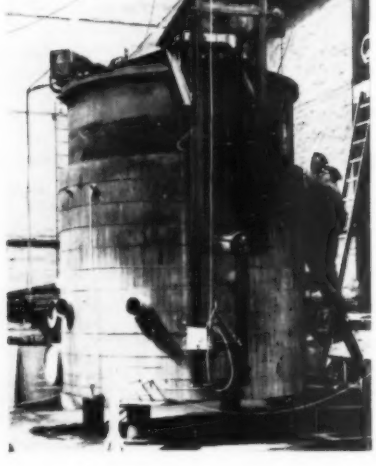
Danish heavy water reactor completed

DR3 is British designed, but both countries took part

ON JANUARY 13, 1960, the DR3 material testing reactor at Riso was handed over by Head, Wrightson Processes Ltd., the main contractors, to the Danish Atomic Energy Commission, DAEC, and four days later criticality was achieved (see *World-view*, last month). This is the first British-designed reactor to be built overseas for which local companies have made a considerable proportion of the components. A few days after the project had been completed Civ. Ing. Roberto Kayser, the DAEC engineer who has been responsible for the international collaboration and construction, told NUCLEAR POWER that they were very pleased indeed with the installation and that by and large everything had gone according to plan.

After arrangements were completed, early in 1957, between the DAEC and the British AEA and Ministry of Works, covering the design, fuelling and technical assistance for the construction of a Pluto-type reactor, the Danes opened negotiations with Head Wrightson Processes Ltd., HWP, who had been responsible for similar reactors at Harwell and Dounreay. During the preliminary talks the DAEC made it clear that Danish companies were to be invited to make as many parts of the reactor as possible. The British at first maintained that only a very small percentage of the work could be carried out in Denmark, but subsequent DAEC analysis and a reappraisal in London made it evident that Danish participation could be satisfactorily extended. From a technical point of view it was thought undesirable to carry out any costly or extensive development work in Denmark for such items as control rod mechanisms, nucleonic instrumentation, and glandless pumps, which had previously been developed by British manufacturers in close collaboration with AERE, Harwell, for the Dido and Pluto reactors. Furthermore, the DAEC stipulated that the main contractors, HWP, were not to carry out any extensive design engineering work which meant that Danish components had to fit into the overall layout without necessitating changes in pipe-layout or other major components, and that existing drawings could be used throughout. This policy was followed right the way down to face-to-face dimensions of valves.

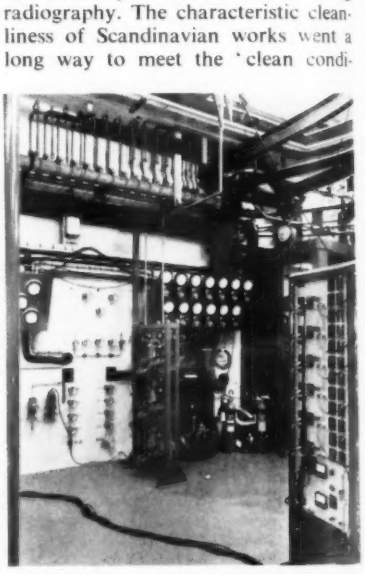
Steel reactor vessel nearing completion at the Elsinor Shipyards



Good delivery times

According to the 'Report on the Activities of the Danish Atomic Energy Commission' for the period April 1, 1958 to March 31, 1959, HWP's estimate for the original contract showed that out of a total cost of £540,679, it was considered possible to invite tenders from Denmark and England for £193,042 and from England alone for £347,637, in fact contracts representing some 30% of the total cost were placed with Danish companies.

The contract between the DAEC and HWP was signed on June 20, 1957 and by July 23, 1957, technicians from the British company were in Denmark evaluating manufacturing facilities. It was expected that inspection and 'clean condition' requirements might cause difficulty. Danish heavy industry, however, particularly in the welding field, rely to a big extent on a centralized and independent inspectorate and the Central Welding Institute of Copenhagen already had facilities throughout Denmark to carry out the testing of welders and inspection of work, including radiography. The characteristic cleanliness of Scandinavian works went a long way to meet the 'clean conditions' and, where necessary, DAEC subsequently provided cleaning facilities and special leak detection equipment. The actual inspection was the responsibility of the main contractor.



Centralized lines and instruments on reactor's lower floor

In the preparation of the overall production schedules, in addition to the normal problems, climatic conditions had to be considered because outside welding is not normally possible during the winter months. Site preparation and foundations, therefore, were critical factors for the first winter and completion of the shell before the second winter was governed by the delivery of the lead-lined steel reactor tank. By September 18,

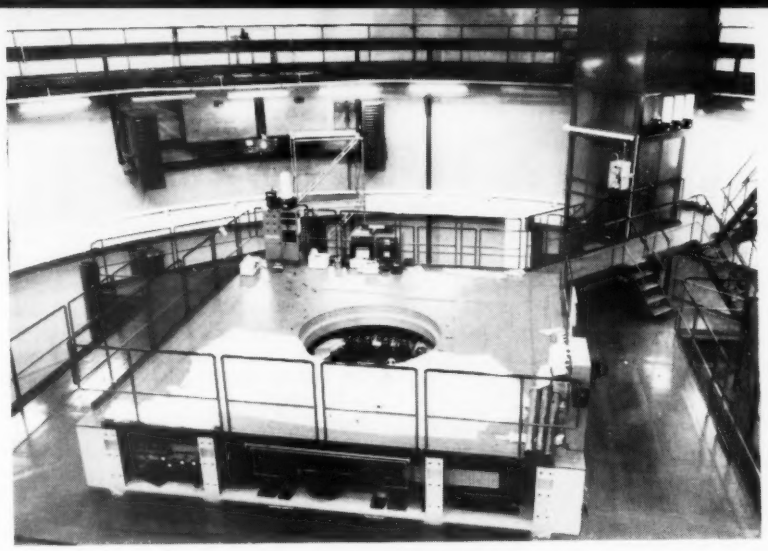
1957, it had been decided that the steel tank would be built by the Helsingor Skibsvaerft og Maskinbygerri A/S and the delivery quoted was very favourable. Despite lack of experience, no appreciable delays occurred and the tank arrived on site on July 16, 1958, which compared very favourably with the delivery time of earlier British tanks of similar type where delays of three or more months were not unknown.

During the autumn of 1957, piling appeared to lag but, through the concentrated efforts of the DAEC, site clearance was completed by the end of November enabling a start on the foundations before the ground became too frozen.

Minor difficulties did arise in the use of British and metric measurements at the same time, but these were overcome to some extent by the Danish use of UK materials. Stainless steel tubing, the key material, however, created a problem. Deliveries from England were so extended that they could not be considered, with the result that welded Danish stainless steel tubing and fittings had to be used instead of the solid drawn type. This procedure incurred additional costs for extensive radiography, but it enabled the original schedule to be kept. The only other major pieces of equipment purchased outside Denmark and the UK were the heavy water stainless steel glandless pumps which, in Dido and Pluto, were of the magnetically-coupled type and had proved to be rather inefficient. Ratier Company of France, who had developed pumps for similar duties, supplied a number for DR3 and it is anticipated that they will have an improved service performance.

British contribution

The fabrication of the complex aluminium reactor tank, which was originally entrusted to Danish manufacturers, did not proceed as planned. Unexpected difficulties arose in the welding and specified tolerances were not held. In the end the cooperation of a British firm, The APV Co. Ltd., was sought and they fabricated the tank under sub-contract from the Danish company, Burmeister & Wain, completing it by March, 1959.



Reactor top—cleaned up design

The first contract placed in England, on October 1, 1957, was for submerged heavy water pumps. Material started arriving on site from Danish suppliers during November 1957, the first English material was delivered on January 3, 1958. By the end of March, 1958, over eighty per cent of the contracts for reactor components had been placed by HWP. One of the major UK suppliers, Ekco Electronics, reduced delivery time and packing costs, by employing air freight from Southend to Kastrup and their Danish agents, Senler & Matthiassen, cooperated in providing 'clean' storage for final checking of the nucleonic equipment prior to transporting it by road to Risø. DAEC's own electronic department helped considerably in the electronic field.

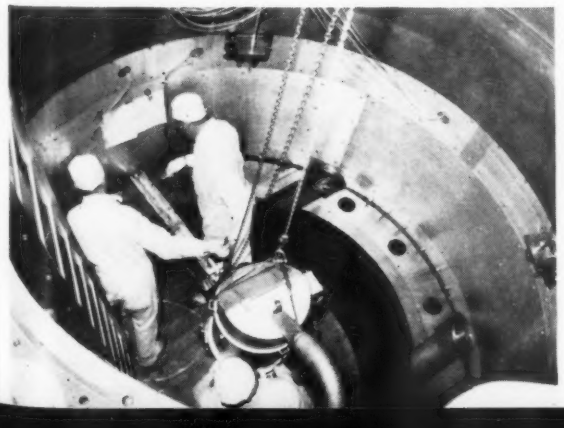
The differences in detailed design between AERE's Pluto in its final form and the DR3 are very few. Certain items have been cleaned up and the electrical power control equipment has been brought into line with standard Danish electrical practices. In principle, the layout of the reactor and its supporting facilities are the same as at Harwell but the buildings have been redesigned to meet the DAEC's high standards of architecture. In the course of these changes the plant room has been turned 90° so that it is now parallel to the administration block and all outside plant has been eliminated. The pump house has been extended to include the extract ventilation plant, the water treatment plant and the air cleaning system. The whole ventilating and air conditioning system has been redesigned to suit Danish standards and the principle of the cooling-heating pump has been employed to gain greater operational economy.

Major design changes

Important changes include: air locks outside the steel shell to prevent heavy condensation, an insulated reactor building and extra clear space in the active handling area. The horizontal facilities storage block has been moved from the middle of the area to outside the actual handling space so that only the front is accessible from the side of the active handling area. The original HWP proposals for fuel handling equipment, which were part of the original contract covered the supply of equipment similar to that made for Harwell and Dounreay. Subsequently the DAEC decided that wet shearing in a pond used at AERE's TIG facility would be employed but that the maximum weight of transfer flasks should be limited to 15 tons and not over 20 tons as in the

TABLE 1

Reactor (including internal storage block)—components	£585,000
erection	£130,000
External fuel element storage block, horizontal and vertical experimental facilities storage block—components	£50,000
erection	£19,000
Reactor building, including services	£300,000
Other buildings	£410,000
Roads, services and ground layout	£70,000



Lead pouring for final bonding within reactor vessel

HWP design. Some 70% of the equipment has now been ordered from Danish companies.

The transfer flask, designed by DAEC, will be capable of cutting off the fuel element plug, removing it and then transferring the element to the pond. There will also be one load/unload flask, three transport flasks, all of HWP design, as well as universal vertical flasks and universal horizontal flasks for use during experiments.

The overall project, including fuel and heavy water, has cost £1,564,000 (table 1).

The UKAEA Industrial Group supplied and machined the graphite blocks for the reactor and the fuel elements.

Originally it was planned to purchase the necessary heavy water from the United States' Atomic Energy Commission at an estimated cost of some £340,000, but DAEC have been able to lease ten metric tons from the AEC. A considerable saving has therefore been made as the DAEC now only have to pay 4% per annum of the official cost of the heavy water at the time of delivery.

As a joint effort between British and Danish companies it has been an interesting project, with the DAEC doing their utmost to help. Labour relations were particularly good and, on the whole, Anglo-Danish co-operation worked smoothly. It does appear, however, that for similar future projects there should be less prefabricated pipework and steelwork as additional cost was involved in remaking some of these components on site.

It is anticipated that DR 3 will achieve its full power of 10 MW late this summer and the first work to be carried out in it will probably be rig experiments for the international Dragon project at Winfrith Heath.

PROGRESS IN INDUSTRY

Machining large nuclear components

Plano-milling cuts machine time

ELECTRICAL components and steam turbine casings have greatly increased in size over the years. The 1912, 25 MW turbo-generator installed by C. A. Parsons in Commonwealth Edison's Chicago Power Station was the largest and most efficient set in the world at that time but, since that date, power demands have grown to such an extent that 250 MW unit designs are not unusual.

Accurate machining of such large units has posed many problems but plano-milling machines for this task have been provided by Kendall and Gent of Manchester since 1926. Their first design was capable of work 16 ft long and this was followed by a 29 ft machine in 1932 and a 35 ft machine in 1947. The latest machine of this series takes components some 35 ft long, weighing up to 100 tons. It is the largest ever built in this country and one of the biggest in the world. The machine is at present being installed in the workshops of C. A. Parsons of Newcastle where it will be used in the manufacture of the very large components required in nuclear power stations.

Remote control operation

Four milling heads are provided, each powered by a 100 h.p. motor and capable of operating with face milling cutters up to 3 ft diameter. The heads are fitted with spindle-retraction equipment and an incremental feed system that enables the operator to set spindles for taking a finishing cut of from 0·010 in. to 0·10 in. by merely pressing a button. The table and milling head traverses are controlled electronically to provide an infinitely variable range of feeds. Further electronic equipment is fitted to give the operator the facility of 'steering' the cutter, by remote control, round any shape of workpiece. Steering is effected by movement of a car-type handwheel which is fitted in each of three control stations, the path steered by the operator automatically determines the speed and direction of the table and cutter head traverses.

Four control desks and two control panels are provided: the master control desk carries controls for operation of the milling head and table rapid and cross-slide traverse; the travelling control desk and the two desks on the horizontal milling heads carry controls for the feed and rapid traverse motions to both table and milling heads. The two control panels on the vertical milling heads provide controls for rapid and feed traverse of the milling heads. All the machine traverses can be operated from the travelling control station where the operator has unobstructed view to permit accurate setting of the machine.

When the machine is operated under steering control, the table and milling head traverse motors are simultaneously controlled allowing 360° travel so that the cutter can be guided round a complicated shape either in the vertical plane or horizontal plane depending upon which milling head is selected for operation. This facility for continuous metal removal on any component irrespective of contour will result in a substantial reduction of machining time.

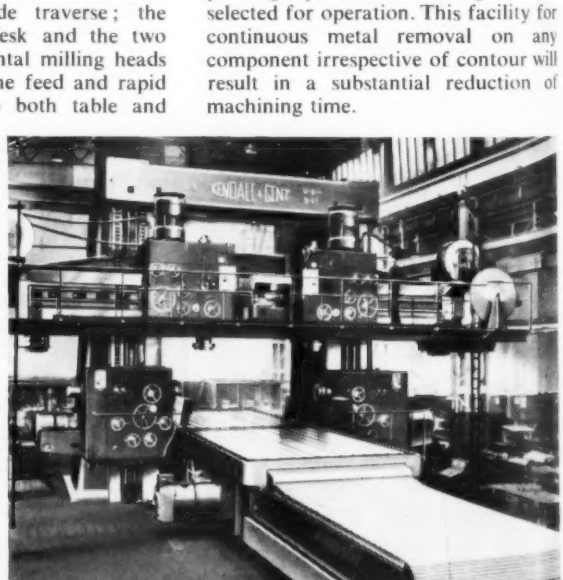


Table and milling-head traverses are electronically - controlled on this 450-ton plano-miller at Parsons' Newcastle works. The cutter can be 'steered' round workpieces of any shape

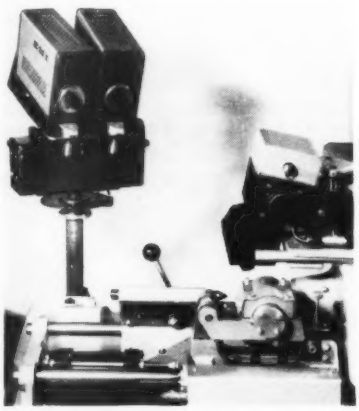
New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

REMOTE CONTROL
stereoscopic TV

An advanced system of stereoscopic closed-circuit television has been developed by EMI Electronics Ltd. to meet the requirements of nuclear plants and other establishments where dangerous materials have to be manipulated remotely.

EMI's stereoscopic equipment uses standard closed-circuit units and consists of two camera channels mounted side-by-side and arranged to relay pictures on two monitors. The pictures from these are then superimposed on each other by means of a mirror and polarized glass to form a single image.



The stereoscopic closed-circuit television of EMI uses two camera channels arranged to relay images of 'hot' materials onto two monitors

When viewed with polarized spectacles this produces a realistic three-dimensional picture. The system is simple to set up and control.

Tick **No 230** on reply card

GAMMA CELL
laboratory experiments

A gamma ray irradiation cell built by Atomic Energy of Canada Ltd., suitable for laboratory experiments and small radiation processing, is marketed in the UK by Watson & Sons (Electro-Medical) Ltd.

The equipment is suitable for irradiation of plastics, radiation chemistry, production of mutations in seeds for agricultural research, the destructive effect of radiation on materials and the preservation of food. It can also be used for the sterilization of pharmaceuticals, surgical equipment and other materials.

The unit which is self contained and can be installed in existing laboratories is simple to operate. Remote handling is not necessary because the external radiation field is very low and no radiation hazard can occur due to mishandling.

The radiation source consists of a ring of cobalt-60 rods, mounted around a stainless steel cylinder embedded in a shielding block. The cylindrical sample chamber is loaded and unloaded above the source, into which it is moved by a motor. The sample volume is 6 in. diameter by 8½ in. high. The irradiation dose rate with a 1100 curie source is approximately 10^5 roentgens per hour but the maximum source strength will depend on working conditions near the cell and will be between 13,000 and 30,000 curies, giving a maximum dose-rate of about 2×10^6 roentgens per hour.

Samples may be irradiated for a preset time, adjustable between 18 minutes and 120 hours and the remaining irradiation time is indicated, if for any reason irradiation is stopped before the desired time is completed.

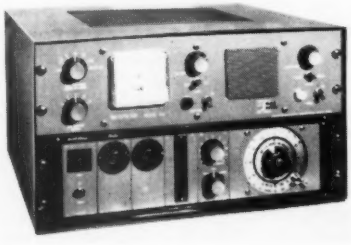
Four ducts connected to the sample chamber allow the entry of pipes carrying liquids or gases and wiring, thus enabling irradiation in a controlled atmosphere to be achieved. The overall dimensions of the whole approximately cylindrical unit are 40 in. by 60 in. by 77 in. high and the weight is 7600 lb.

Tick **No 231** on reply card

ISOTOPE COUNTER
versatile scaler ratemeter

A versatile radioisotope counting assembly, the Scaler Ratemeter Model 555, has been developed by Baird-Atomic, which combines in a single instrument an advanced scaler, precision-ratemeter, integral-analyser, spectrometer-quality high voltage supply and audible clicker-howler.

The Model 555 ratemeter of Baird-Atomic is a compact instrument for medical isotope work combining all basic elements



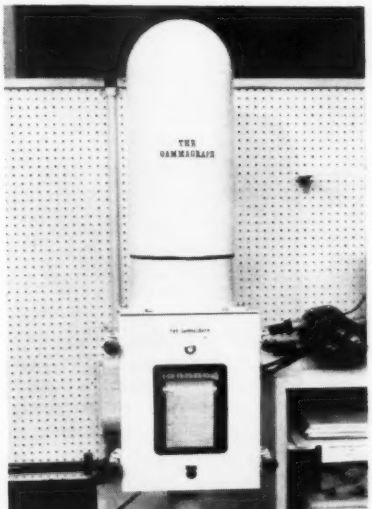
Operating with any geiger or scintillation detector, it provides in one compact package all basic elements needed for medical isotope work. Features include simultaneous digital and analogue displays, precision discrimination for integral analysis, a stable high voltage power supply, a preset and elapsed-timer, and audible 'howler' for precise localization studies. This scaler ratemeter combination can be adapted to localization studies, integral scintillation analysis, geiger counting, dynamic studies, uptake measurement and spectrometer systems.

Tick **No 232** on reply card

DOSERATE METER
recording gamma radiation

A new mobile Gammagraph, Model 65A, developed and manufactured by Electronic Instruments Ltd., Richmond, Surrey, records accurate and continuous measurement of gamma radiation in or out of doors.

Three preset ranges enable accurate records to be kept of gamma radiation levels from natural background up to 10 mr/h, with sensitivity very nearly quality independent from 60 keV to 2 MeV.



Electronic Instruments' Gammagraph is a serviceable doserate meter for continuous recording of fall-out or rise in background radiation

It consists basically of an ionization chamber, 18 inches long, containing a special mixture of gases under pressure, mounted vertically on a hermetically-sealed case containing the electrometer circuits and a clockwork-driven recorder. The recorder trace can be observed through a glass panel without opening the instrument and all controls are mounted internally to avoid unauthorized

interference. Power for one month's continuous operation is provided by a conventional 12 volt, 40 ampere-hour car battery. Except for one electrometer valve, the circuit is fully transistorized.

A transistorized electrometer drives a 1 mA recorder to full scale with currents as low as 10^{-12} amp. and linearity and stability are assured by high overall feedback. Overall dimensions of the unit are 30 in. by 9 in., its weight approximately 70 lb., and power consumption less than 0·5 watt.

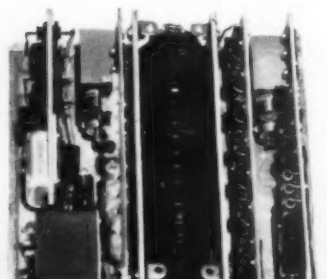
Tick **No 233** on reply card

ATOMIC GAUGE
new gamma application

A transistorized atomic energy gauge has been developed for the US Navy by Atomics International which measures the amount of fuel in airplanes and missiles with greater accuracy and reliability than conventional devices.

All types of solid and liquid propellants can be measured and performance is not affected by impurities in the fuel.

It consists of gamma radiation sources, such as cobalt-60, scintillation detectors



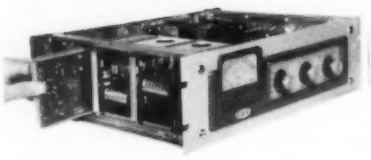
AI's transistorized lightweight radiation gauge has been tested for the US Navy for accuracy up to 38,000 ft

containing a ratemeter and pulse amplifier, a power supply and an indicator. Radiation sources and detectors are mounted on the sides of each fuel tank. Gamma rays given off by the radioactive materials decrease in intensity as they pass through the fuel and the amount of fuel is determined by the intensity of the gamma rays reaching the detectors. The ratemeter converts pulses picked up by detectors into d.c. voltage and the quantity of fuel is recorded in pounds by the indicator.

Tick **No 234** on reply card

COUNTING INSTRUMENTS
new I.D.L. range

Isotope Developments have introduced a new series of budget-priced nucleonic counting instruments designed to combine



Typical of I.D.L.'s 1800 Series is the Amplifier Discriminator Type 1830. Note plug-in printed circuit

accuracy, flexibility and easy maintenance. The instruments are supplied in attractively styled cabinets with tilt-up stand so that they can be used singly or stacked one above the other. They can also be converted readily to rack mounting. Since all connectors are mounted at the rear and the cabinet is fitted from the front, access can be obtained to the interior without disconnecting cables.

Printed circuit plug-in boards are used extensively throughout and an identical power pack is fitted in all units to simplify spares requirements and servicing. Each instrument after 100 hours test is despatched with a fully detailed service manual and packaged spares kits can be provided at the same time.

The first three members of the 1800 Series now available for delivery are the Scaler, type 1800, the High Voltage Supply, type 1820 and the Amplifier/Selector, type 1830. Further announcements will be made shortly concerning the Ratemeter, type 1810, the Prescaler, type 1850, the Potentiometer Unit, type 1840, and other units of the '1800' Series.

Tick **No 235** on reply card

AUTOMATIC CALCULATOR
increases output

A new desk calculating machine has been introduced by Diehl that claims fully automatic multiplication from a single keyboard with self explanatory X and = keys. The machine finds the shortest way through any calculation: viz: to multiply 987492 the machine takes only 2·4 seconds. This new technique is said to increase the rate of output by more than 50% over all conventional calculators, with almost silent operation and less maintenance cost.

The decimal point to all answers is found automatically and in division the entry of the factors, the decimal point in the answer and the lining up of the figures are all automatic operations.

Tick **No 236** on reply card

MILLIVOLTMETER
high stability performance

A new vibrating reed electrometer, Type N616, has been introduced by Ekco Electronics. Designed to measure very small direct currents and voltages with high zero stability, Type N616 converts applied d.c. to a.c. by means of a vibrating reed capacitor and amplifies it by a stable a.c. amplifier.

Seven ranges are provided—3, 10, 30, 100 and 300 mV and 1 and 3 V. The output is rectified and measured on a 5 in. panel meter calibrated to indicate the d.c. voltage at the input.

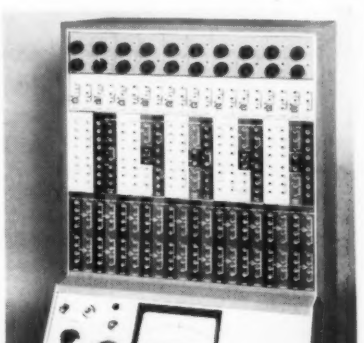
For voltage measurements, accuracy is about ± 5%, while current measurements may be made to the same accuracy provided that the total value of the input resistance is known and the calibration control is adjusted as necessary.

Tick **No 237** on reply card

DESK COMPUTER
new low-price U.S. model

Electronic Associates (USA) have developed a moderately priced analogue computer that can perform most routine mathematical operations found in normal design calculations. Completely transistorized, the Pace TR-10 occupies little more desk top area than a standard electric typewriter. Claimed accuracy is 0·1%.

The computer is designed to make analogue computation easily accessible for every engineer and to provide him with first-look solutions, especially on dynamics problems, in a fraction of the



The Pace TR-10 has 10 amplifiers but it can be expanded to 20 if necessary. Several units can also be combined

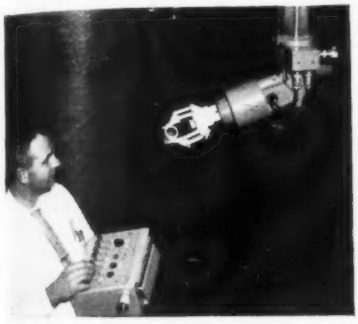
time they normally take. Modular construction allows selection of varying quantities of the following computing functions: summation; integration; multiplication or division; function generation, parameter adjustment; logical comparison. The price starts from just under $4000 and includes 10 operational amplifiers.

Tick **No 238** on reply card

POWER MANIPULATOR

economy model from U.S.

A new electro-mechanical manipulator has recently been developed by the Mechanical Division of General Mills to meet the needs of the smaller type of nuclear laboratory. Known as the Model 100 Mechanical Arm, it is claimed to



The General Mills Model 100 manipulator can handle loads up to 200 lb and features a new type of portable control

be the first remote-control, powered manipulator to be offered commercially in the price range of master-slave manipulators.

The Model 100 permits an operator to work from a remote, shielded location and to perform high-precision tasks inside a sealed radioactive area. Viewing may be by closed circuit TV or directly through a specially-designed lead-glass window. The new device has high dexterity and extremely rapid response rates.

Tick **No 239** on reply card

RADIOGRAPHY

High Voltage microwave linacs

Two new linear accelerators for radiography have been announced by High Voltage Engineering Corporation (USA).

One of the new models, the 8-MeV Model LR-8, is designed specifically for high-speed, precise radiographic inspection of extremely thick sections of steel and of complex mechanical and electronic assemblies encountered in the nuclear and missile industries. The other, the 15-MeV Model LR-15, is designed for high-speed precise radiographic examination of solid rocket propellants.

The LR-8 machine offers a dual X-ray output of 6000 r/min, from a 5 mm focal spot and, for greater precision, 1500 r/min from a 1 mm focal spot, with intensities measured at a 1 metre distance from the source. Electron energies are continuously variable from 2–8 MeV. At the maximum, the intense X-ray output of the LR-8 permits shorter exposure times for thick sections by at least a factor of ten compared with other high energy radiographic means.

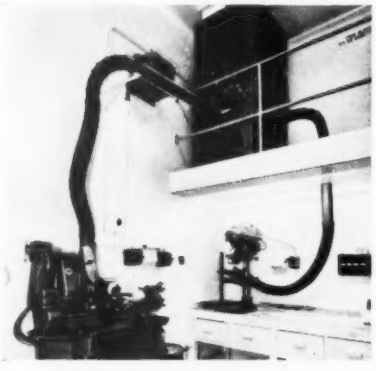
The compact design of the new machines permits a variety of mounting arrangements. They can be permanently installed by means of an overhead crane suspension mount or can be truck-mounted to provide the greatest flexibility at the point of use. Price of either machine is approximately $150,000 plus mounting.

Tick **No 240** on reply card

DUST EXTRACTION

clean machining conditions

Standard dust control equipment made by Dallow Lambert has been adopted for use at AERE, Harwell. It controls the dust created during machining operations on reactor components. Static installations provide an almost absolute extraction while by adding a flexible pipe to the unit dust collector, it can be moved about and used as a cleaning nozzle. The dust entrained into the collector is arrested on the surface of the fabric filter pads, and is subsequently dislodged from the filter surface by a mechanical



Clean air conditions are maintained during machining at AERE, Harwell, by the use of Dallow Lambert equipment. The flexible unit can also be used as a general purpose cleaning nozzle

shaking device. Being slightly radioactive, the dust is collected in a polythene bag within the collecting bin to facilitate safe removal.

Tick **No 241** on reply card

ULTRASONIC CLEANING

quick-change filter

Dawe Instruments Ltd. have introduced a filter unit (Type 1181) for the continuous removal of solid matter from ultrasonic cleaning baths of their own or other design. Fluid is drawn from the bottom of the cleaning bath by a centrifugal pump and returned to the top of the bath through a sintered stainless steel element capable of removing all solids down to a size of below 2 microns from 8 gallons of liquid per hour. Coarser filter elements are available to give flow rates up to 60 gal/h. Changing elements either for cleaning or to obtain a different pore size takes less than a minute.

All metal parts in contact with cleaning fluid are of stainless steel. The interconnecting tubing is of extruded nylon. All parts are thus easily cleaned and, if necessary, sterilized.

Tick **No 242** on reply card

IN BRIEF

Microswitches. Data sheet from Honeywell Controls Ltd. illustrates an example from each series of their range of microswitches including a sub-miniature switch ·35 in. × ·2 in. × ·5 in.

Tick **No 243** on reply card

Electric Motors. New English Electric range of totally-enclosed fan-cooled motors—type O—have outputs double the old type B with frame sizes undamaged.

Tick **No 244** on reply card

Variable transformers. Research & Control Instruments Ltd. are marketing a new Philips model with separate primary and secondary windings. Two types are available—for bench use and panel mounting.

Tick **No 245** on reply card

Tube expanders. Charles Wicksteed & Co. have introduced a new automatic torque control unit (Mk IV) for use with conventional electric drill type expanders. Normal tube sizes handled are $\frac{3}{8}$–1 in. o.d.

Tick **No 246** on reply card

Scanning Unit. Research & Control Instruments Ltd. have available a new Philips Scanning Unit (PW.4083). Designed mainly for use with Philips' Single Channel Pulse Height Discriminator (PW.4082), it is also suitable for other types.

Tick **No 247** on reply card

Non-magnetic tools. Made from *Berinkle* —gold-plated, heat-treated beryllium-copper to DTD 900/4433—a range of non-magnetic, spark-proof tools is being manufactured by C. Brandauer & Co. Ltd. First available is a set of BA spanners at £2 2s.

Tick **No 248** on reply card

Computers. First production models of Ferranti's Orion data-processing system are due complete soon. Fully transistorized, Orion is claimed to be one of the fastest systems in the world. Cost, depending on size and scope, will fall in bracket £100,000–£300,000.

Tick **No 249** on reply card

Fail to safe for any electro-pneumatic system can be achieved with the Saffail valve. Its design is such that there is five times the force available to move from 'on' to 'off' than for it to move from 'off' to 'on.' If this differential drops, through any fault, the valve is locked 'off' until the fault is rectified.

Tick **No 250** on reply card

INDUSTRIAL NEWSDESK

New US fuel deals

Nuclear Materials & Equipment Corp., NUMEC, have received a contract for some four tons of specially fabricated fuel material for use in critical experiments in connexion with the US nuclear superheat development programme. The order was placed by the Nuclear Division of Combustion Engineering Inc., and NUMEC will both produce the uranium dioxide powder and, in its ceramics plant, fabricate the powder into sintered shapes. Most of the uranium dioxide to be provided is to be in the enriched U-235 form.

Another large American fuel contract has been awarded to Mallinckrodt Nuclear Corporation to supply some 1000 kg of 93% uranium oxide for the Consolidated Edison Company's Indian Point project. Mallinckrodt will process the fuel before passing to Babcock & Wilcox Co., at Lynchburg, to be homogeneously mixed with thorium oxide and fabricated into fuel element pellets for installation in the PWR.

Outlet for isotopes

Continuing the drive to expand the industrial uses of radioisotopes, a team of consultants from the Wantage Research Laboratories of the UKAEA visited Manchester during the first half of February. The visit was sponsored by the Manchester Joint Research Council and the Manchester Chamber of Commerce. An exhibition illustrated such industrial uses as:—measuring and controlling the thickness of rolled steel and paper; automatic check on the contents of packages; and weld testing. Already the application of isotopes to industrial purposes in the UK has resulted in the saving of several million pounds per year.

More work for US firms

There is still plenty of work for the American nuclear industry. Over the past few weeks the AEC and industrial groups have issued contracts involving several millions of dollars. As a basis for negotiations, the proposals by the Fluor Corporation, for the architect-engineering services covering the experimental organic-cooled reactor, have been selected by the Commission. Congress has appropriated some $M6 for this facility which has to be flexible enough in operation to work at either 20 MWt and a temperature of 700°F, 40 MWt and a temperature of 500°F or at any intermediate power levels and temperatures.

Another experimental facility under construction is the EGCR at Oak Ridge. Valued at some $M1·7, a subcontract has been given to Pittsburgh-Des Moines Steel Company for the containment shell and air locks. This will have a height of 216 ft and a diameter of 114 ft and, with an average thickness of ¾ in., will contain approximately 1250 tons of steel.

Under the AEC programme for Puerto Rico, a new bio-medical building is to be constructed by Francisco Levy Hijo of San Juan and it is expected to be completed by the end of October 1960. Another new research building is that for the new cyclotron at Oak Ridge and the total project, including the cyclotron and auxiliary equipment, is expected to cost nearly $M4.

Two other new facilities at Oak Ridge are a radioisotope development laboratory and a transuranium laboratory; overall architect-engineer services for all three projects are being provided by the Catalytic Construction Company.

To develop the instrumentation and control of their 9·35 MWt PM-1 air transportable packaged power reactor. The Martin Company have given a six-month study contract to the Stromberg-Carlson Division of General Dynamics.

Cleaning up at Oak Ridge

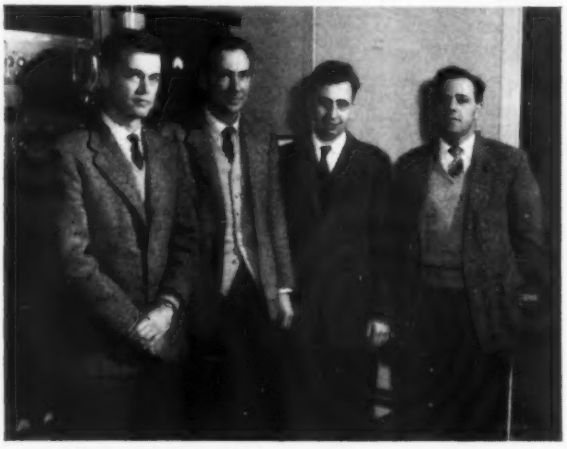
Decontamination of the area affected by a small chemical explosion on November 20 at the Oak Ridge National Laboratory has been completed. The estimated cost for carrying out this cleaning is between $250,000, and $350,000. The accident occurred in a cell of the Thorex Pilot Plant which had been used for processing waste products for the recovery of plutonium and other transuranium elements. The run had been completed and cleaning up was in progress when the accident occurred. An organic solvent was being used which apparently exploded and scattered approximately 600 milligrams of plutonium.

Checking Einstein

A team of scientists in the Nuclear Physics Division of the AERE, Harwell, using gamma rays from a source of radioactive iron, have completed two experiments which appear to confirm the basic premise of Einstein's General Theory of Relativity. These experiments were planned by Dr. T. E. Cranshaw and Dr. J. P. Schiffer.

The source for this work was prepared on the University of Birmingham cyclotron by bombarding an iron target for one hundred hours with a beam of deuterons. It was subsequently purified at the Radiochemical Centre at Amersham with the final processing of both the source and the absorber being carried out by the Chemistry Division of AERE.

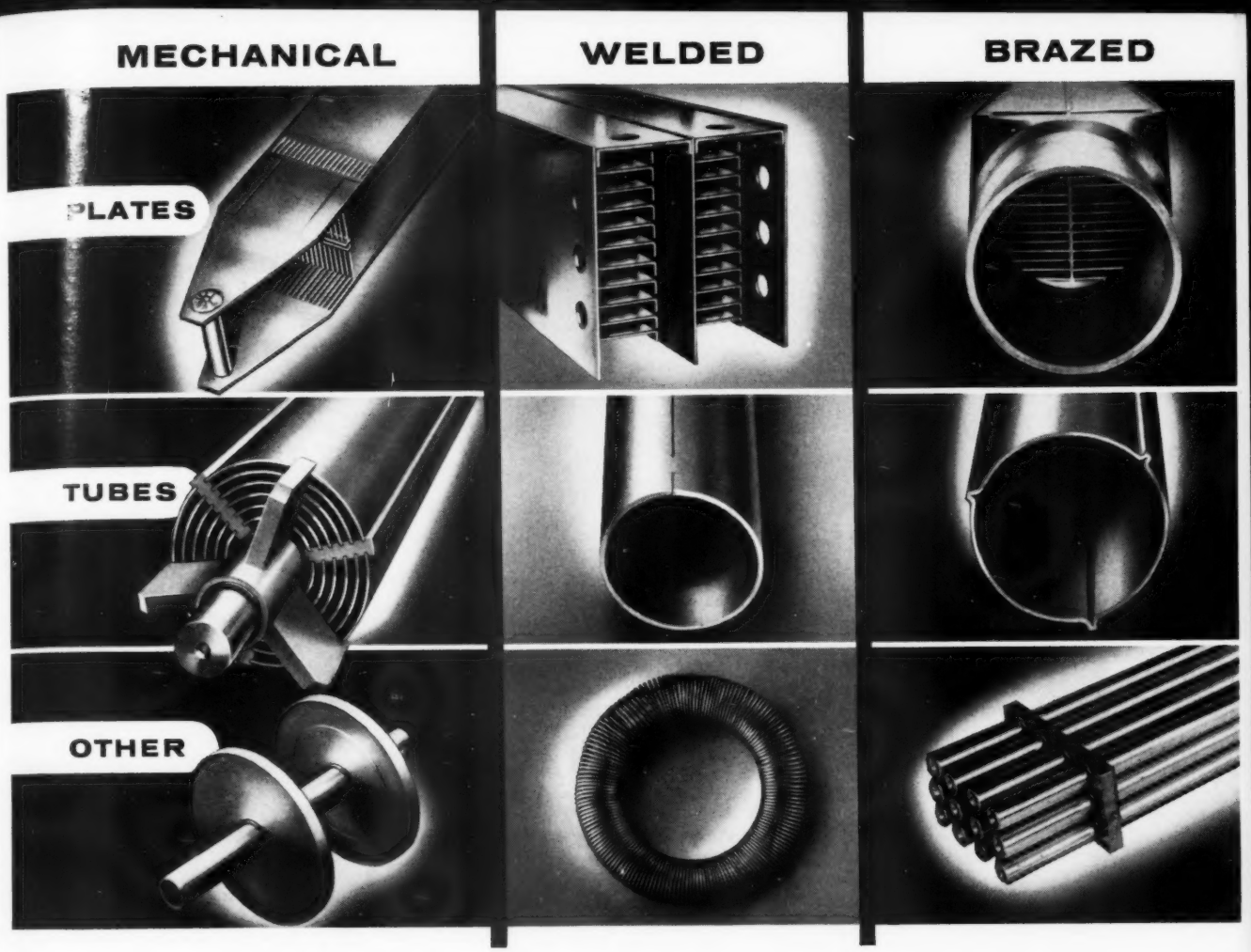
Of use in astronautics to indicate whether a body is accelerating or not, the two experiments illustrate the Principle of Equivalence. The first was concerned with the red shift, the effect of gravitational fields on electromagnetic radiation, and the second with the fact postulated by Einstein that there should be no detectable difference between a uniform gravitational field and acceleration. Here the source was placed in the centre and an adsorber at the outside surface of a cylindrical rotor. By spinning the rotor up to velocities of 30,000 revolutions per minute, accelerations up to 65,000 times as large as the acceleration of gravity of the surface of the Earth were obtained. By checking the variation in number of gamma rays passing through the adsorber at different velocities of rotation it was possible to check Einstein's premise. The results observed were in line with the effects predicted by Einstein. Further experiments, with improved accuracy, are planned for the near future.



JOINT RESEARCH The four scientists who have been investigating Einstein's theory of relativity at Harwell, left to right, Dr. A. B. Whitehead from Canada, Dr. T. E. Cranshaw of Southport, Lancs., Dr. J. P. Schiffer from the US and Dr. H. J. Hay from New Zealand

Joint research

Nuclear Development Corporation of America, NDA, are to carry out research and development under the joint US-Euratom programme. Based on a pro-



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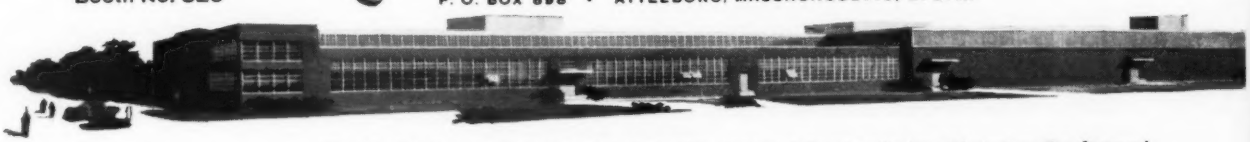


The World's Largest Privately Owned Facility Designed Specifically for Fabrication-Development and Production of Fuel Elements, Core Components and Complete Cores.

Tick **No 87** on reply card for further details

AGR PROGRESS The first section of the No. 1 heat exchanger, weighing some 84 tons, has been completed by International Combustion. Each of the four heat exchangers will consist of three such sections

posal submitted in cooperation with two Italian companies, CISE and Ansaldo, and estimated to cost some $550,000, the project will cover the engineering design and experimental investigation of the 'fog cooling' method for power reactors. It is based on the use of high pressure steam and water droplets, where some or all the droplets are evaporated into steam when passing through the reactor. The steam is then passed directly to the turbo-generators.

Changes in British industry

Richardsons Westgarth & Co. Ltd., one of the companies associated with Atomic Power Constructions Ltd., have formed a US subsidiary, Richardsons Westgarth Inc., located at Washington. It will act as selling agent for the UK parent company and as main contractor where plant is made in America to British designs.

Operating in the reverse direction is the appointment of New Metals & Chemicals Ltd., as UK distributors of 'Hyperpure Silicon' produced by Trancoa Chemical Corporation and includes semiconductor grade polycrystalline and single crystal material.

To improve site service, Durapipe & Fittings Ltd., manufacturers of thermoplastic rigid pipe and fittings, have merged with the Plastic Division of H. Incledon, Ltd. Overall range will be sizes from ¾ in. to 6 in. and of high impact PVC, Kralastic and high density Ziegler polyethylene materials.

The Timkin Roller Bearing Co., and The Fafnir Bearing Co. of New Britain, Connecticut, have come to an agreement whereby a recently formed subsidiary of the latter, Fafnir Bearing Co. Ld., have purchased the Fischer Bearings Co. Ltd., until now a Timken subsidiary.

Albert Mann Engineering Co. Ltd., have obtained a manufacturing licence from the Loma Machine Mfg. Co. Ltd., and its subsidiary, Lobeck Casting Processes Inc., for their range of metal processing equipment. The agreement extends to the Outer Seven countries of the European Free Trade Association and the British Commonwealth, excluding Canada.

So as to achieve close cooperation in the forming and fabrication of complete units, N. C. Ashton Ltd., and W. P. Butterfield Ltd., are now working together. Already large water and return boxes for a tubular exchanger in aluminium bronze to ASTM B 169 Alloy D have been successfully made for the petroleum industry.

IN BRIEF

Pumps for Trawsfynydd. Hayward Tyler & Co. Ltd., have received a contract from International Combustion Ltd., for twenty-four each low and high pressure glandless pump and motor units for a total value of some £100,000.

AEC buys from Germany. Seven gas centrifuges for use in a pilot-scale study to determine the commercial feasibility of a process for production of enriched uranium have been purchased by the US Commission from Dr. Konrad Beyerle of the Institute of Instrumentation, Aachen.

Instrument expansion. The Victoreen Instrumentation Co., of Cleveland, has acquired John E. Fast & Co., a Chicago firm mainly concerned with the development and manufacture of capacitors.

Power station equipment. Tracerlab have been awarded two large reactor monitoring contracts. One, valued at $110,000, will be installed at the Detroit Enrico Fermi fast breeder plant, and the other, valued at approximately $65,000, will be installed at the first organic moderated power reactor at Piqua, Ohio.

Export opportunities. The Federation of British Industries has issued a new booklet 'European Free Trade Association.' It gives a brief historical background, the terms of the Convention and basic materials lists as well as import duties and quotas.

Windscale detection system. Avo Ltd., have received a contract from the UKAEA to install criticality incident detection system at Windscale. The system was designed by the Authority for radiation detection in the second plutonium processing plant now being constructed.

US progress. The 165-ton reactor vessel for the Yankee Atomic Electric Company plant at Rowe has been delivered. It was built by Babcock & Wilcox for the Westinghouse Electric Corp., who designed the nuclear plant.

New facilties. Ekco Electronics are building a new factory at Rochford, Essex, which will be devoted to the manufacture of electronic and nucleonic equipment.

Handling services. At a cost of some $300,000, AEC have awarded an architect-engineer contract to Hummel, Hummel & Jones, to design a MTR-ETR storage and receiving building at the NRTS, Idaho. It will include storage vaults, cask storages and decontamination areas.

Graphite storage. While it will only take 3–4 months to install the cores of the two reactor vessels at Hunterston, Powell Duffryn Carbon Products' constant output for the 2000 tons of machined blocks will extend over 2½ years. To meet this difference in time, the GEC have established a graphite and other core component storage at Daly, Ayrshire.

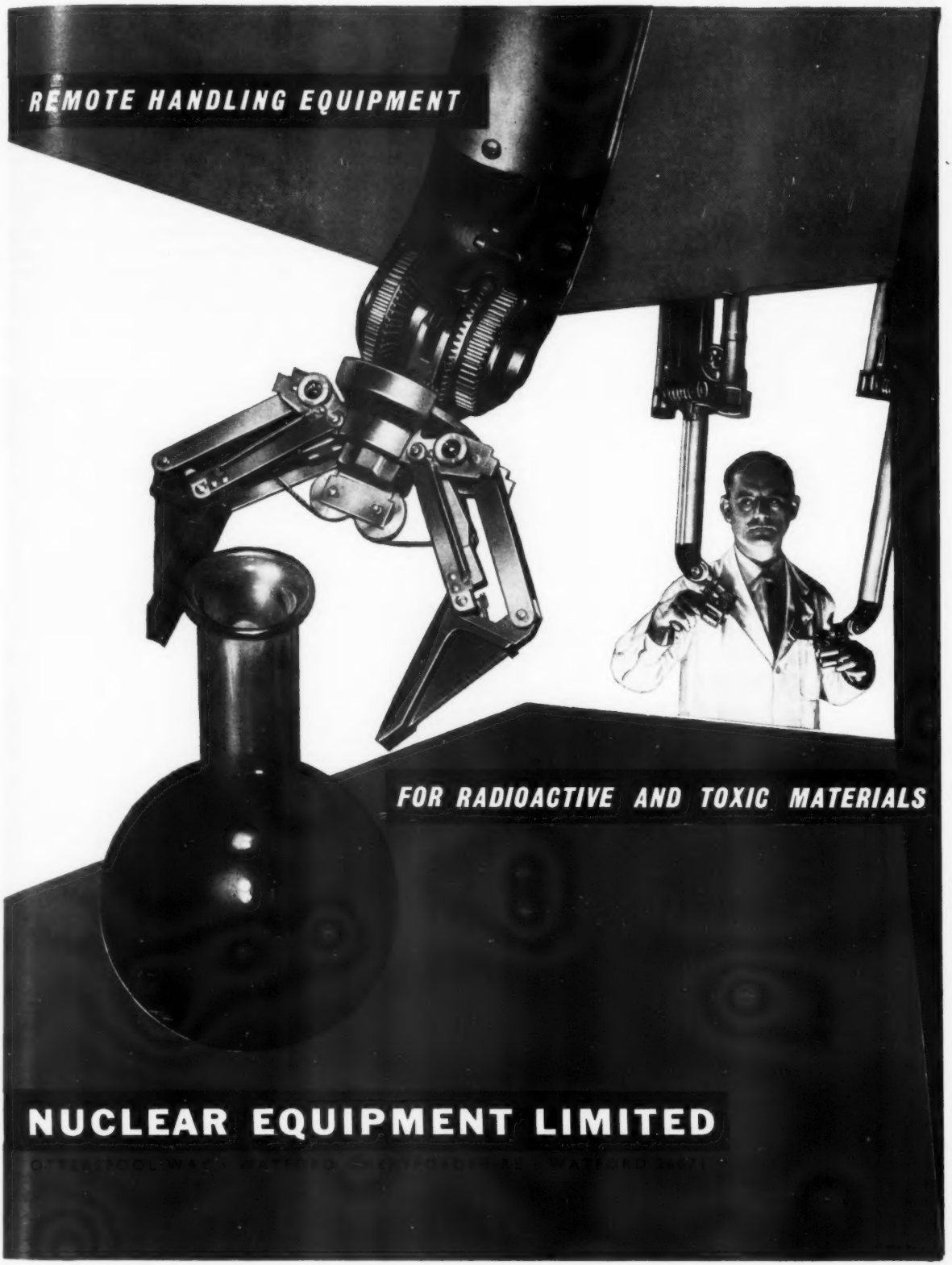
Air Force protection. The USAF have awarded a contract to Controls for Radiation Inc., for the installation, calibration and maintenance of all nuclear radiation protection services at the USAF Cambridge Research Centre.

Repeat order from China. Griffin & George Ltd., of Alperton, have received another order, valued at £8000, for gas-liquid chromatographic analysis apparatus. This will bring the number of such instruments now in use in China up to nine.

Still working well. While SNAP-3, the miniature atomic generator, was intended to operate for a period of some 140 days without maintenance, it is still producing electricity after a full year of continuous operation.

Research furnace. The GEC, in association with Vacuum Industrial Applications Ltd., are supplying a vacuum melting furnace to the British Iron & Steel Research Association for use in their Sheffield Laboratories.

Quick success. Although Taylor Electrical Instruments only introduced their new edgewise meters a couple of months ago, 4000 of them have already been ordered.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They said...

points from papers, speeches, conferences

New find in Canada

Following the detection last summer by the British American Oil Co. of helium in significant proportions in a wildcat well at Swift Current, more big oil firms are taking considerable potential acreage in south western Saskatchewan and the provincial government has had to draw up a special exploration and development permit for helium only, reports *The Financial Post* of Toronto. Reviewing these finds, Mr. Winnett Boyd, President of Winnett Boyd Ltd., has said 'the significance of this Saskatchewan helium discovery can hardly be exaggerated. Plentiful native helium, along with enriched uranium, could put Canada in an enviable position in the nuclear era.' He added that for the worthwhile development of high temperature gas cooled nuclear power reactors, helium is a must. Already Texaco Exploration, Sun Oil, Mobil Oil, Richfield Oil and a syndicate of smaller oil companies have obtained development permits and joined the British American Oil Co. in prospecting for helium.

American HTGR development

Already consideration is being given in the US to the use of helium as a cooling medium. At the recent international forum at the Franklin Institute, Dr. Peter Fortescue and Corin L. Rickard of General Dynamics Corporation's General Atomic Division described the 40 MW prototype HTGR plant under development for the High Temperature Reactor Development Associates Inc. Rickard stated that the fuel temperatures and gas pressures will be approximately the same as those required for larger plants. 'For this reason,' he said, 'there is sound reason to believe that later HTGR plants of 300 MW size, scaled up from this prototype, will be able to produce electric power at a cost of about 7 mills per kilowatt hour which is generally regarded as the target for competitive nuclear power in many areas in the US!

Rickard added 'this estimate does not assume improved performance over that of the prototype in terms of reactor outlet temperature, power density or other improvements resulting from current developments. Consequently, even further reductions in the cost of such reactors can be expected when taken to the ultimate development stage.' This HTGR features fuel-moderator elements of uranium and thorium carbide dispersed in graphite which, with helium gas cooling, allow an outlet gas temperature of 1380°F. This will enable the maximum use of modern steam-turbine conditions, steam at 1000°F and 1400 lb/in² or higher, and will give a net thermal efficiency for the plant of approximately 35%.

Prospects in the UK

An optimistic assessment for the future was also given by Mr. Philip Honey, of the British Electrical Development Association, when he recently addressed a conference at Penkhull. He said 'the future of fuel and power would be a dismal story—of ever decreasing supplies in the face of an increased demand—were it not for the prospect of nuclear energy. For many years it could only make a small contribution to the country's electrical needs, but by 1965–66 there would be some 12 to 15 nuclear power stations at work generating a total of between five and six million kilowatts. The magnitude of this amount could be compared with the present demand for electricity which on one cold day in January of last year reached a record of 20 million kilowatts. By 1965, however, this peak demand might well have increased to 36 million kilowatts or even more.

P. HONEY of EDA
a dismal story

Costly marine controls

Doubts were cast on present control rod philosophy for marine propulsion reactors at a recent meeting of the Institute of Marine Engineers. 'The cost alone of present control equipment, especially that shown in the OMR designs of Atomics International, will equal the whole of the steam power plant which the reactor system replaces' maintained Dr. Bauer of Rolls-Royce. He was taking part in the discussion following the paper on reactor control and instrumentation by Messrs. Anscomb and Hutber of AEA, Risley. Mr. Anscomb had pointed out that control systems have to be precise and reliable so that none of the components will be subjected to excessive temperature and pressure variations during normal changes in power or through minor faults and accidents. He referred to present complicated designs and noted that the characteristic of load following in certain types of reactor could be used to reduce the amount of external control. 'The highly enriched PWR submarine reactor does this by exploiting density and temperature coefficient effects' he said. 'The natural circulation BWR is not a load following system because control rod movement is too slow to meet the increased demand when the pressure drops and the moderator flashes into steam.' He suggested that better stability and load following could be obtained by adapting a dual cycle, thus making the reactor a cross between a PWR and BWR.

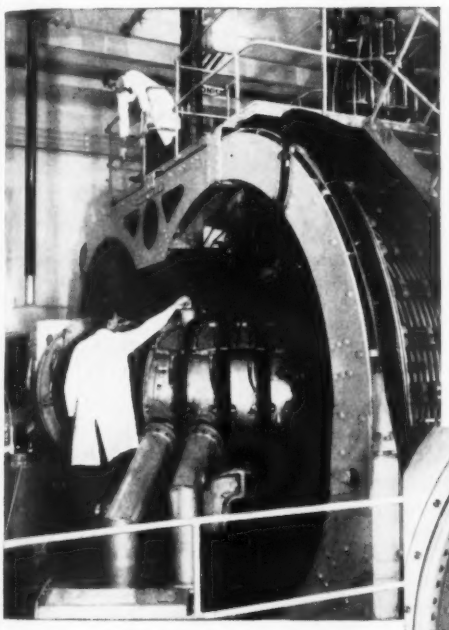
Following their criticism of OMR control philosophy Dr. Bauer and Capt. Atkins of Vickers added that the deciding factor governing the choice of systems should be the avoidance of too many trip circuits and the minimum of control gear. 'Liquid control is a possible answer, using moderator flow for simpler control design by applying "unmoderation" instead of poisoning.'

The criticism of the OMR control instrumentation did not go unchallenged. Mr. Bracewell of APC said 'present design is necessarily complicated until operational experience has been gained, particularly with some aspects of organic heat transfer under transient conditions.' Mr. Anscomb, in supporting this, emphasized that triplicate safety circuits safeguarded possible failures in control mechanisms and electronic equipment. At this stage of development, an accident could not be tolerated, he said, 'it would set back the programme for so many years.' Another speaker thought that the case for liquid control was oversimplified and that the real issue was the demand for an economical, yet safe, nuclear merchant vessel at a time when so many fundamental problems were still to be solved. No doubt, in time, instrumentation systems will be evolved that will make the present designs seem excessive and lavish. In the intervening period, however, the introduction and construction for practical familiarization of at least one system is essential.

TEDDINGTON BELLOWS
and Nuclear Power
HARWELL PAYS A TRIBUTE

Harwell top research scientists have freely acknowledged * that recent improvements in the operational efficiency of Zeta owe much to the introduction of a corrugated stainless steel liner inside the aluminium 'torus'. Having decided to use such a liner, they turned to Teddington engineers who, out of their experience in adapting their bellows expansion joints to various demands in a wide field of industry, produced exactly what was required for satisfactory running over long periods.

* *In a paper read before the I.E.E. on 29/30 April 1959 by Mr. J. T. D. Mitchell of the U.K.A.E.A., Harwell*



In Zeta, experiments towards controlling fusion have resulted in gas temperatures of several million degrees centigrade being achieved for millisecond periods. View showing the torus.

This stainless steel liner has improved operational characteristics and requires less maintainance than the original aluminium liner system. Here is part of the twelve welded sections of Teddington stainless steel bellows tube of wall thickness 0·017"; it has 2½ convolutions per inch of a depth of 0·75". The bellows is 38 inch bore and the whole toroidal bellows assembly has an axial length of 37 feet and an electrical resistance of 0·02 ohms.

SEND FOR HANDBOOK R. 33

Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.

ZETA

Teddington Bellows are produced in technical collaboration with the Solar Aircraft Co., U.S.A.

TEDDINGTON
STAINLESS STEEL BELLOWS

TEDDINGTON AIRCRAFT CONTROLS LTD. (*Industrial Bellows division*)
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PEOPLE

by John Radford

I was sorry to hear that due to a heart complaint, Academician **Igor Kurchatov** died on February 7, at the age of 57. He was the director of the USSR Academy of Sciences' Atomic Energy Institute and was one of Russia's most outstanding physicists. His work in the nuclear field began as long ago as 1935 and by 1940 he was directing research into the spontaneous fission of uranium nuclei. In later years had directed his activities into the fields of thermonuclear reactions and the industrial use of nuclear energy.

Nearly a year after the post was established, **Dr. David A. Senior** went to Moscow last month to become the first scientific attaché from a Western country in the USSR. His main duties will be to foster the exchange of information

Dr. D. A. SENIOR
understanding the Russians

and visits of personnel in the broad field of general science. His first work will be, as he puts it, 'to understand their system' and not act as a general clearing house for information requested by scientists or industrialists in either the USSR or the UK.

Another appointment intended to widen overseas knowledge of British technical know-how is the new post of Director of Technical Assistance in the Commonwealth Relations Office. The first director is **Mr. A. H. P. Humphrey,** CMG. OBE. He joined the Malayan Civil Service in 1934 and has had considerable experience in the Far East.

Changes in both organization and staff continue to be made at Risley. The AEA have made **Mr. H. Cartwright** Director of Industrial Power in the Authority's Development and Engineering Group. He was previously deputy director of the same department and has been with the AEA since 1949 when he joined the Atomic Energy Division of the Ministry of Supply at Risley as a design engineer. A new appointment at the same establishment is that of General Manager (Commercial) at the Production Group Headquarters and the main duties will be the negotiation of contracts for the sale of

H. CARTWRIGHT
Risley's power chief

uranium fuel elements to home and overseas markets. **Mr. J. B. Laurie,** BSc(Eng), MIEE, is to be the first to hold the post and I feel his extensive

J. B. LAURIE
to sell fuel for AEA

knowledge of the western hemisphere should prove of great use when the uranium market becomes a 'free for all' in the next few years.

Senior engineers continue to leave the Authority to go to industry. The latest is **Mr. K. R. Sandiford** who was an Assistant Chief Engineer at Risley and is now General Manager of Hagan Control Ltd. I hear he is at present in the US studying the various systems manufactured by the parent company and he expects to introduce their new electrical systems into nuclear applications in the UK.

Recently returned from Japan where he signed, on behalf of the GEC/Simon-Carves Atomic Energy Group, a £M20 contract for the construction of the Tokai-Mura power station, **Mr. R. N. Millar,** a Director of The General Electric Co. Ltd., has been appointed Managing Director of the company's Engineering Group.

Changes in the ICI Metals Division have been announced. **Dr. Maurice Cook,** who has been Chairman for the past two years, retired from the Company's service on December 31, 1959. He has been succeeded by **Mr. Michael Clapham,** a joint Managing Director. At the same time **Mr. G. A. D. Smith** has been made Commercial Managing Director. He was originally appointed to the Board of ICI Metals Division in 1951 and has since served as Sales Director and Commercial Director.

General Dynamics Corporation's General Atomic Division has appointed **Mr. Titus G. LeClair** as manager of nuclear power applications. Coming from the Commonwealth Edison Co., he will be responsible for expanding development of commercial applications for General Dynamics' power systems. This includes the 40 MW HTGR to be completed in 1963 for the Philadelphia Electric Company.

Sir Owen Wansbrough-Jones, KBE, CB, has been appointed a director of The British Oxygen Company Ltd.

To fill a vacancy on the board of directors of The Babcock & Wilcox Company

W. H. FELDMANN
joins American B & W Board

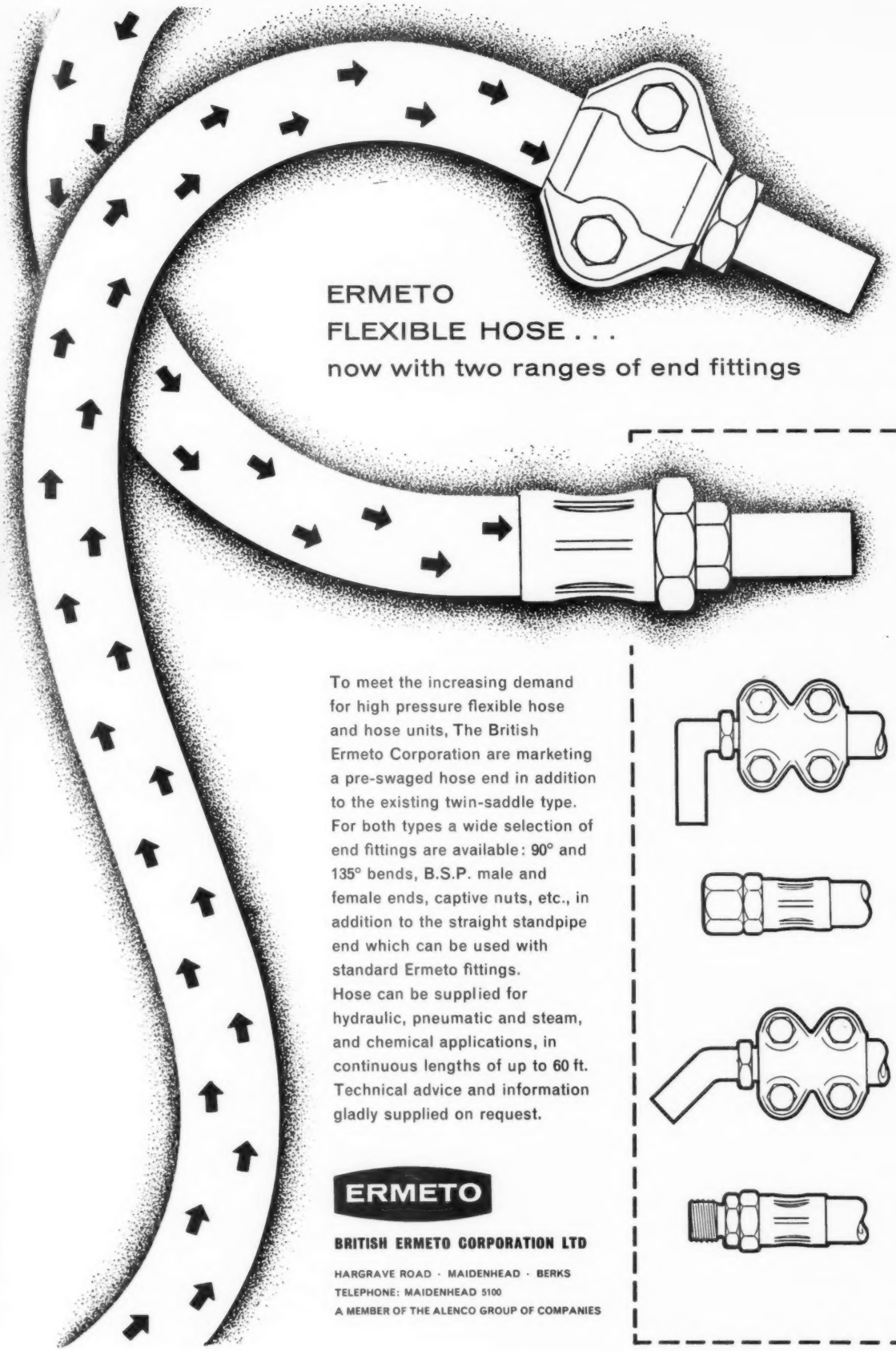
created by the death of **Vice-Admiral Edward L. Cochrane,** USN(Rtd), **Mr. Walther H. Feldmann** has been elected. Since 1957, Mr. Feldmann has been president and director of Worthington Corporation.

After having been Chairman for ten years and Managing Director for twenty-five years, **Mr. Richard Miles** retired from Head, Wrightson & Co. Ltd., at the end of January. **Sir John Wrightson,** Bt., Vice-chairman, and Managing Director

Sir JOHN WRIGHTSON
new head at Thornaby

for the last ten years, has been appointed to succeed Mr. Miles as Chairman and Managing Director.

Consequent on the resignation of **Mr. G. H. Hopewell** from the managing directorship of Foster Wheeler Ltd., **Mr. C. E. H. Verity, OBE,** will become Managing Director and will continue as Manager, Steam Division. At the same time, **Mr. R. B. Kerr, MBE,** becomes Deputy Managing Director and Manager, Process Plants Division as **Mr. H. T. Collinswood** has retired from the post of Manager, Process Plants Division. He will, however, remain a director of the company.



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LOOKING AHEAD

MARCH 2
The Role of Formal Education and Training in Nuclear Power Developments (Discussion) The Institution of Mechanical Engineers 6.00 at 1 Birdcage Walk, Westminster, London, SW1
MARCH 3
Biological Hazards of Radiation Prof. J. Rotblat Institute of Physics 7.30 at Aberdeen University, 7.15 at Edinburgh University on March 4, 7.15 at Glasgow University March 7
Future Generation and Transmission Development in Scotland J. Henderson Institution of Electrical Engineers 6.00 at Kilmarnock
MARCH 8
Transistor Power Amplifiers F. Butler British Institution of Radio Engineers 7.15 at Matthew Boulton Technical College, Birmingham
MARCH 9
Power, Flow and Pressure Measurements in Pump Testing L. Young and R. A. Nixon Institution of Mechanical Engineers 6.00 at 1 Birdcage Walk, London, SW1
MARCH 9
Recent developments in heat transfer O. A. Saunders. The Institution of Chemical Engineers 7.00 at the Houldsworth School of Applied Science, University of Leeds, Leeds, 2
MARCH 10
The Harwell Protonsynchrotron P. Bowles Institution of Mechanical Engineers 7.30 at Technical College, Reading
MARCH 11
Powder Metallurgy Applications B. H. Swann Institution of Mechanical Engineers 7.30 at Technical College, Gloucester
MARCH 14–25
Course on Sanitary Engineering Aspects of Nuclear Energy Robert A. Taft, Sanitary Engineering Centre at Cincinnati, Ohio, USA
MARCH 14—JULY 31
Automatic Industrial Inspection Equipment Exhibition Production Engineering Ltd., at 12 Grosvenor Place, London, SW1
MARCH 15
Applications of Thermo-electricity Prof. D. A. Wright Institution of Physics 6.15 at King's College, Newcastle-upon-Tyne
MARCH 15
Effect of Nuclear Radiation on Engineering Materials Prof. A. H. Cottrell Institution of Mechanical Engineers 6.00 at South Wales Electricity Board, Swansea
MARCH 16
Power from Nuclear Energy M. D. Wood of Ruston and Hornsby Institute of Plant Engineers 7.00 at King's Head Hotel, Rochester, Kent
MARCH 16
Recent Impressions of the Soviet Union D. F. Galloway Institution of Production Engineers 7.00 at Midland Hotel, Birmingham
MARCH 16
The Simulation of a Large Chemical Plant on an Electronic Analogue Computer A. H. Doveton and K. C. W. Pedder The Society of Instrument Technology 7.00 at Manson House, 26 Portland Pl., London, W1
MARCH 17
Prospecting for Radioactive Minerals F. H. Hale Society of Instrument Technology 7.15 at Nottingham and District Technical College, Burton St, Nottingham
MARCH 21
Recent developments in Scintillation Counting Dr. J. B. Birks Institute of Physics 7.15 at Edinburgh University 7.15 at Glasgow University on March 22
MARCH 21–22
The Computer in Production an informal discussion and visits to computer centres. Applications to The Secretary, The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, SW1
MARCH 22
Neutron Sources P. O. Hawkins Institute of Physics 5.40 at 47 Belgrave Square, London, SW1
MARCH 24
Direct Conversion of Heat to Electricity Dr. Dunn Institution of Mechanical Engineers 6.45 at Engineers Club, Albert Square, Manchester
MARCH 25
New Uses of Glass in Industry B. H. Turpin Institution of Production Engineers 7.30 at South Wales Institute of Engineers, Park Place, Cardiff
MARCH 29
Applications of Transistors in Instrumentation G. G. Bloodworth, the Society of Instrument Technology 7.00 at Manson House, 26 Portland Place, London, W1
MARCH 29–31
Symposium on chemical process hazards with special reference to plant design, the North Western Branch of the Institution of Chemical Engineers. Details to be announced later
MARCH 29—APRIL 1
Exhibition of Drawing Office and Photoprinting Equipment Lawes Rabjohns at Bristol
MARCH 29—APRIL 1
Symposium on Fatigue of Welded Structures The British Welding Research Association and the Engineering Department, Cambridge University. Further details The BWRA, Abington Hall, Abington, Cambs
MARCH 30
Electro Magnetic Flow Meters L. M. Bennett. The Society of Instrument Technology 6.45 at the Physics Lecture Theatre of the Welsh College of Advanced Technology, Cardiff
APRIL 3–8
Sixth Nuclear Congress, Nuclear Engineering Conference, International Atomic Exhibition and Eighth Atomic Energy in Industry Conference at New York, USA
APRIL 5–9
Ninth Electrical Engineers' Exhibition at Earls Court, London, SW5
APRIL 6–8
Solid State Microwave Amplifiers Conference. The Institute of Physics at the University of Nottingham. Applications to The Secretary, The Institute of Physics, 47 Belgrave Sq., London, SW1
APRIL 7
Rapid Magnetic Compression in a Deuterium Plasma Leonard M. Goldman of GE Research Laboratory Northwestern University, Evanston, Illinois, USA
APRIL 7
The Work of the B.S.I. in Relation to the Radio and Electronics Industry H. A. R. Binney British Institution of Radio Engineers 6.30 at London School of Hygiene, Keppel Street, London, WC1
APRIL 8
Nuclear Fuel Element Inspection R. S. Sharpe Institution of Physics 6.00 at 47 Belgrave Square, London, SW1

LOOKING FURTHER AHEAD

APRIL 19–22
International Symposium on the Metallurgy of Plutonium. Session on Nuclear Fuels. Société Française de Métallurgie and Commissariat à l'Energie Atomique at Grenoble, France
APRIL 21–22
Training of the Industrial Physicist Symposium at Birmingham Applications to Secretary, Institute of Physics, 47 Belgrave Square, London, SW1
APRIL 25–29
International Compressed Air and Hydraulics Exhibition Empire Hall, Olympia, London
APRIL 25–29
Sixty-seventh Annual Health Congress of the Royal Society of Health at Torquay
APRIL 25–30
Fourth Production Exhibition at the National Hall, Olympia, London, W14
APRIL 26
Some Recent Advances in Industrial Electrical Control Techniques T. E. Barany The Society of Instrument Technology 7.00 at Manson House, 26 Portland Place, London, W1
APRIL 26
Sealing against pressure and vacuum Joint meeting of the Institution of Chemical Engineers and the Institute of Petroleum at Manchester
APRIL 27—MAY 6
Fuel Efficiency Exhibition Grand Hall, Olympia, London

CATALOGUES AND BULLETINS

Aircraft to power stations. The latest issue of the Fairey Review includes details of Trawsfynydd power station.
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Solidal cable. A bulletin from Northern Aluminium describes their new cable which makes the fullest use of the properties of aluminium as a conductor and of p.v.c. as an insulator. This cable is particularly easy to lay and joint.
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The uses of precious metals. The January number of 'Platinum Metals Review' includes articles on palladium plating of printed circuits, iridium platinum alloys and platinum metals in potentiometers.
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Nucleonic equipment. A new catalogue has been issued by Ekco. It includes comprehensive descriptions of a wide range of instruments in which not only full performances are given but extensive physical measurements.
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Development facilities. The Fall number of Skyline reviews in some detail the research facilities that are necessary to investigate high and low temperature operations. Another facility incorporates a number of hot cells.
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Knitted metals and plastics. New leaflets from KnitMesh cover various types of electronic shields which are being used in the electronic and nucleonic industries. A general information sheet lists the types and thicknesses of materials used for meshes.
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Making use of new metals. Of a general introductory nature, ICI Titanium—Wrought Products, describes the manufacturing facilities, production range and the principal outlets for titanium and titanium alloys.
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To meet the new laws. Two leaflets issued by Con-Rad are particularly suitable at the present time. One covers bio-assays for hazard control and the other advanced film badge dosimetry.
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Special purpose furnaces. Metalectric leaflet M.4B describes their box type furnaces suitable for precision heat treatment for all temperatures up to 1000°C.
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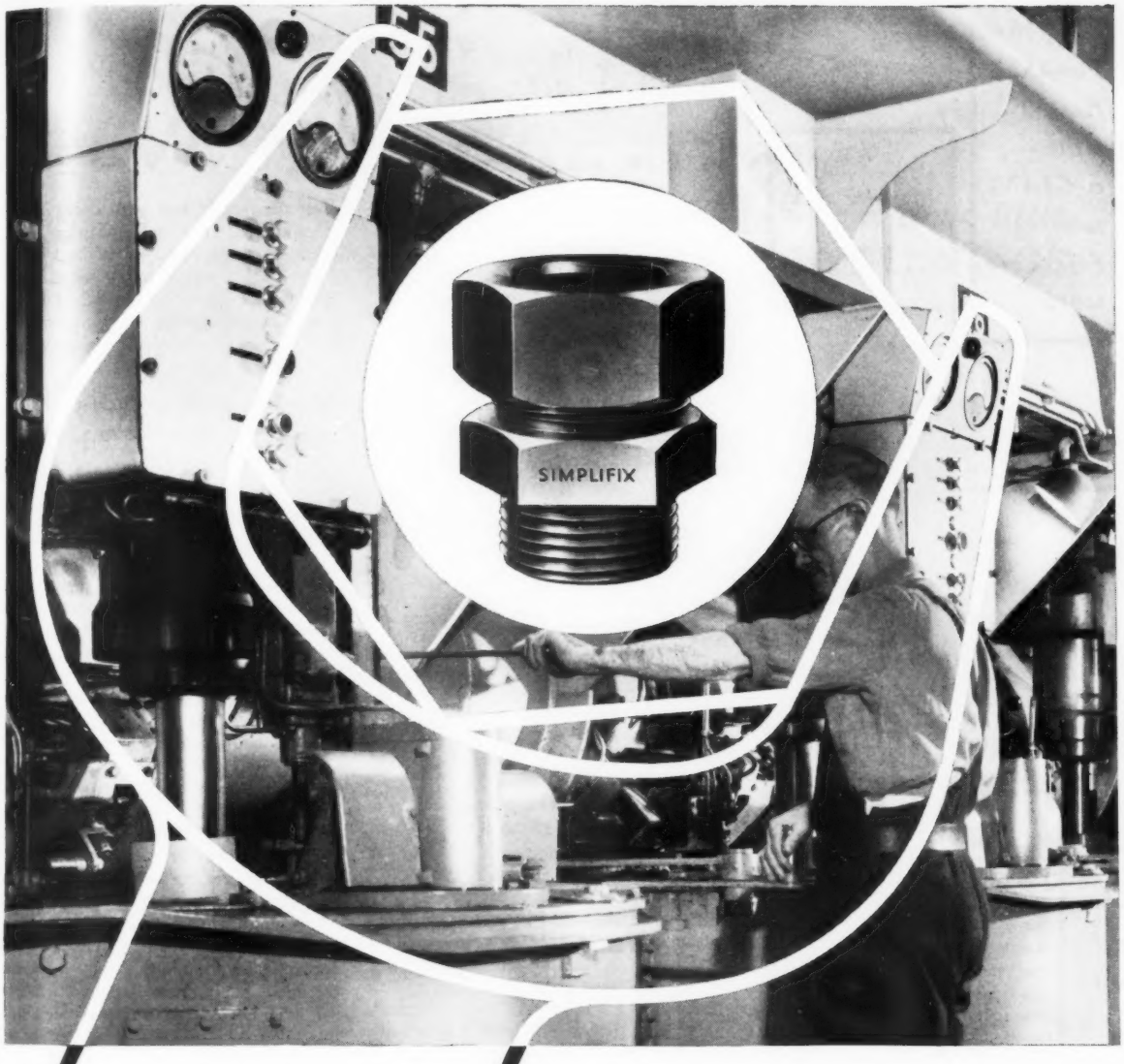

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Book Reviews

Plutonium plant problems

Windscale: Problems of Civil Construction and Maintenance by Stuart Sinclair. London 1959: Newnes 136 pp Price 25s.

There is a particular fascination in the history of great projects pushed through under 'crash' programmes. When a brilliant team of engineers and scientists is limited, not by a shortage of money or equipment, but by a lack of precedents and experience, the results of their efforts are worthy of serious study. Often in such cases the point of interest is the one blunder which sticks out among thousands of difficult decisions wisely and correctly made. Windscale was one such project. Only seven years ago very few people knew anything at all of what went on inside the fence and even today many of the activities there are secret. In 1954 the Ministry of Supply published "Britain's Atomic Factories", which gave a fairly full story of Windscale in laymen's terms ("Great fans . . . hurling air through big concrete channels"). Since then we have had to piece together the technical details from intermittent publications and this book is to be welcomed as a major contribution to the story of the factory.

The author is a Clerk of Works at Windscale and the book is said to be addressed mainly to civil engineers and construction personnel. It would be a pity if this dedication prevented engineers of any persuasion from reading it. Mr. Sinclair's interests range far beyond the niceties of concrete mixes. The first chapters discuss the building of the major structures and, in particular, the two plutonium-producing reactors which are now derelict. The story is told, so alarming in retrospect, of how the outlet air filters were a last-minute design change and had to be mounted at the top of the stacks which were by then well on in construction.

The chapters of outstanding interest are those which deal with the emergency measures taken to correct errors in construction or design. The charge wall, for example, containing hundreds of accurately aligned stainless steel charge tubes, cast into shielding concrete, was found on completion to be riddled with voids. Lesser men might have ripped it down and started again, losing six months in the process. The author tells us how the voids were patiently located, cut into with diamond drills, and filled with grout under pressure without delaying the programme. Other 'impossible' remedial work which is described includes the cutting of ducts through shield walls after the reactor had been operating for three years. The last chapter is an account of the highly organized system of preventive maintenance used at Windscale. The illustrations which form an essential part of the story are copious and clear.

R. F. V. Guard

Nuclear marine propulsion

Jane's Fighting Ships 1959-60 by Raymond V. B. Blackman London 1959: Sampson Low, Marston & Co. Ltd. 478 pp Price £5 5s

In its sixty-second year of issue, this traditional standard work of reference on the navies of the world now enters the field of nuclear marine engineering. Details of nuclear-propelled vessels, both surface and under-surface naval units, built and at present under construction in Russia, the United Kingdom and the United States of America are given. Also reviews proposals for nuclear submarines for the comparatively small navies of France, Italy and Japan.

As most recent recommendations for the future application of nuclear propulsion for surface vessels advocate the use of closed-cycle gas turbine circuits, it is interesting that a number of ships are already using conventional gas turbines and this issue of Jane's provides details of such ships' characteristics and performances. Similarly, recent proposals for initial nuclear installations have been for fast fleet replenishment ships and this book reviews existing and proposed vessels in this class.

Reviewing the United States Navy, the construction programmes for the years 1957, 1958, 1959 and that proposed for 1960 are included and show that some thirty nuclear propelled vessels are being put into commission. Looking to the future, it is anticipated that 150 ships with nuclear-powered machinery plants will be built for the USN by 1970. Altogether some 10,000 ships in the navies of 70 countries are fully described and many of them are illustrated by photographs or scale drawings.

New Books

- *Health Physics in Nuclear Installations* Risø Symposium May 25–28, 1959 Paris 1959 OEEC 410 pp Price 37s 6d
- *Basic Electricity and Basic Electronics*, 11 parts US Navy and British War Office London 1959 Technical Press Each part 12s 6d, 66s the set
- *Directory of Nuclear Reactors*, volume II: research, test and experimental reactors Vienna 1959 International Atomic Energy Agency 348 pp Price 21s

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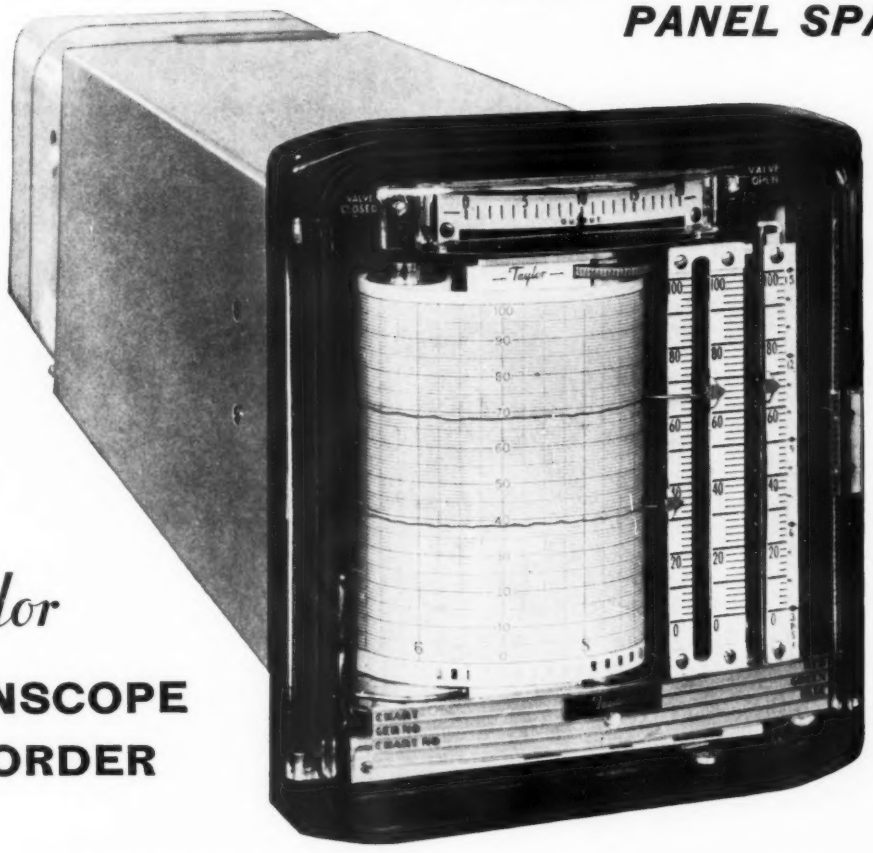

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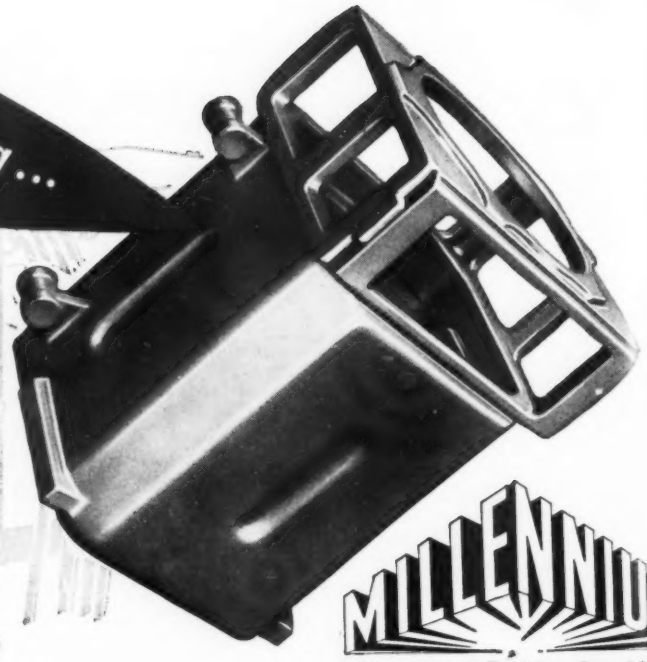

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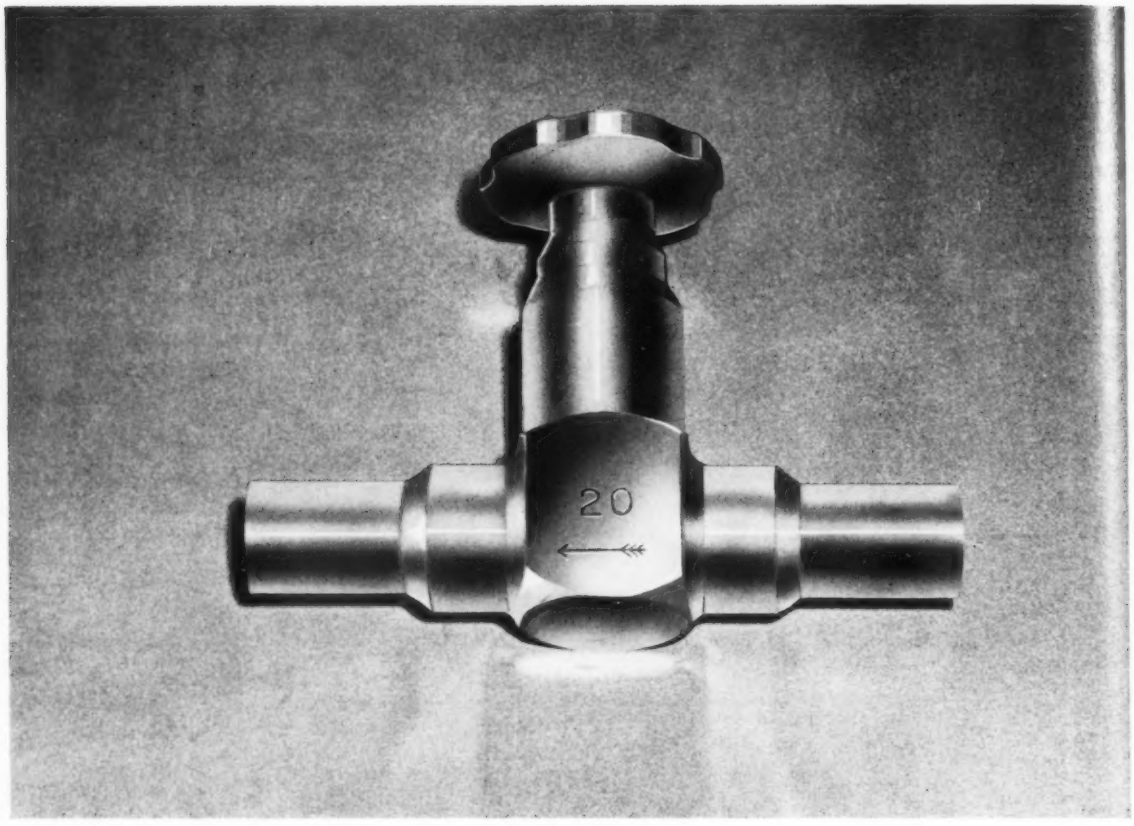

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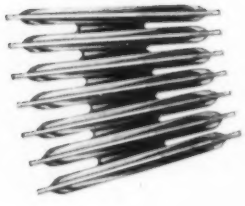

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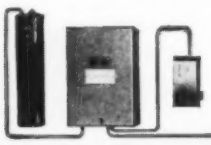

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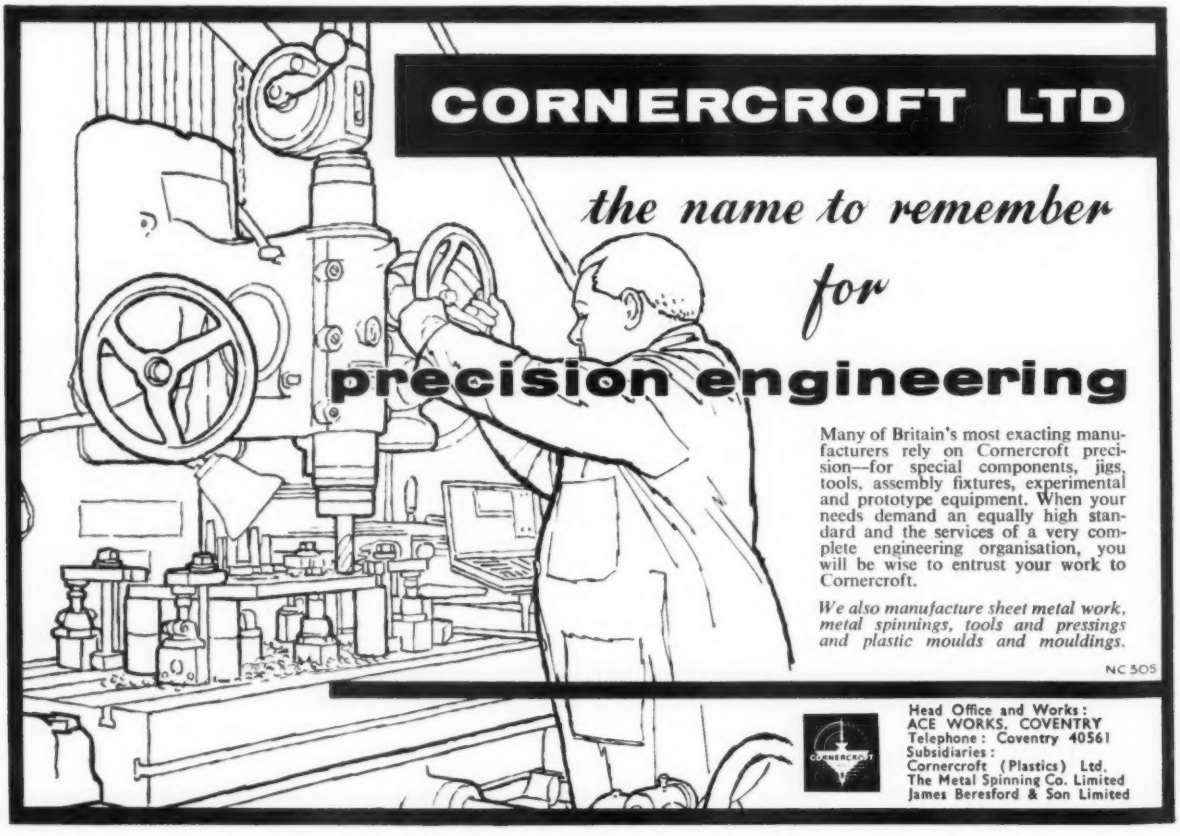

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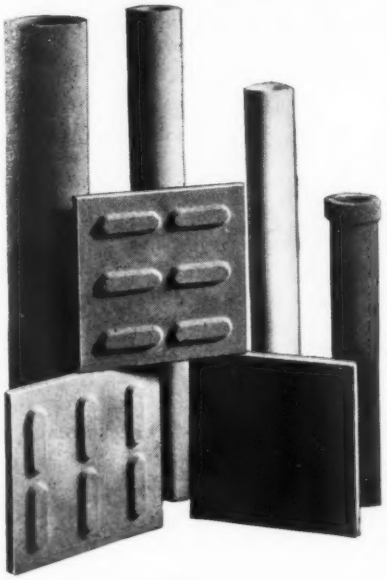

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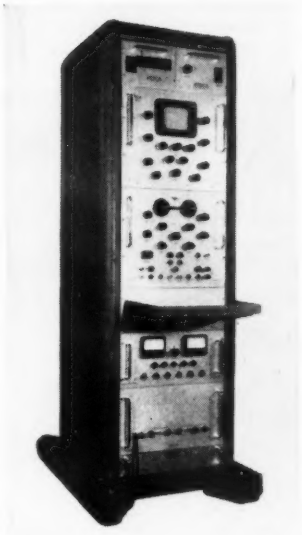

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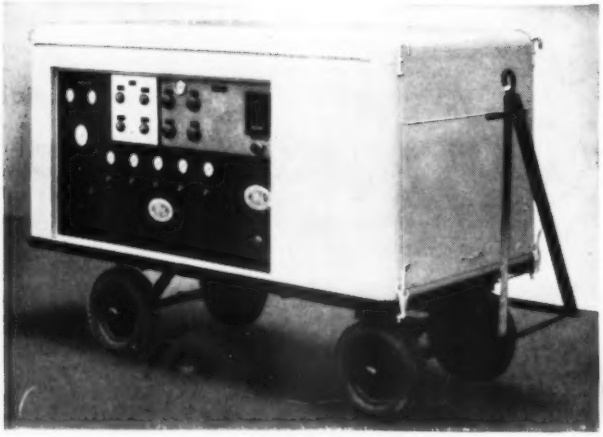
Please write for Leaflet No. 19 giving full details.



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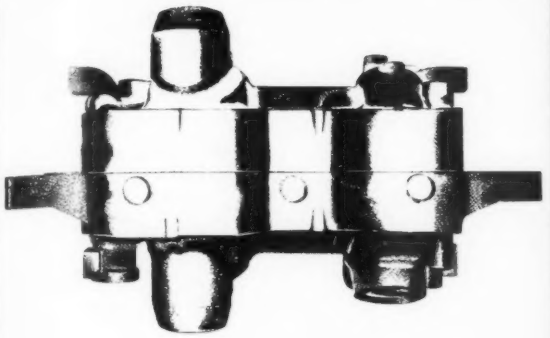

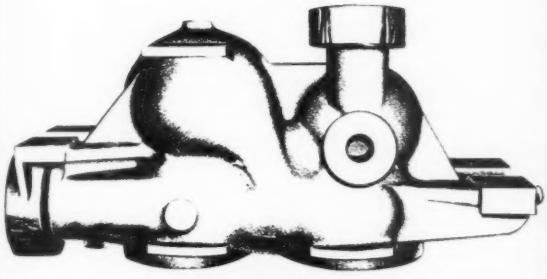

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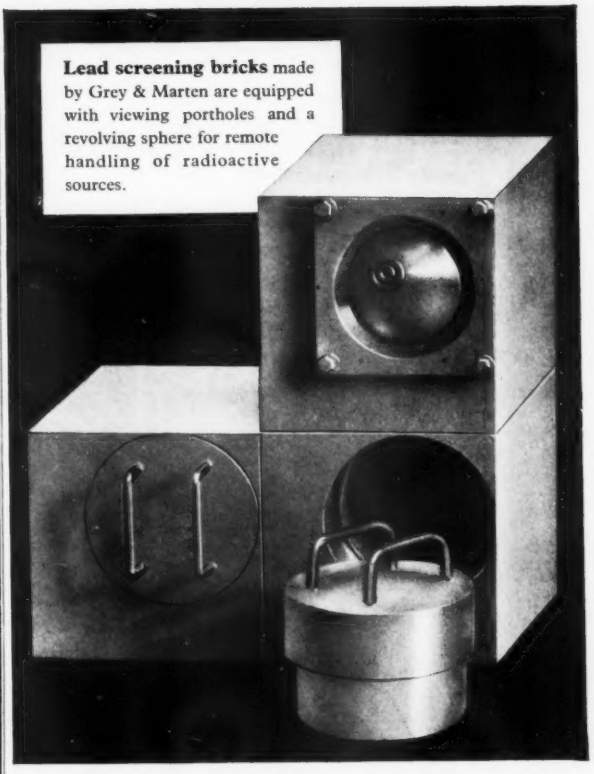

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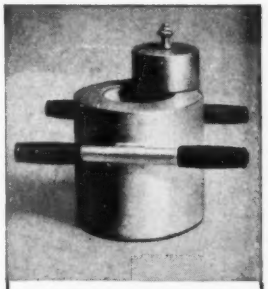

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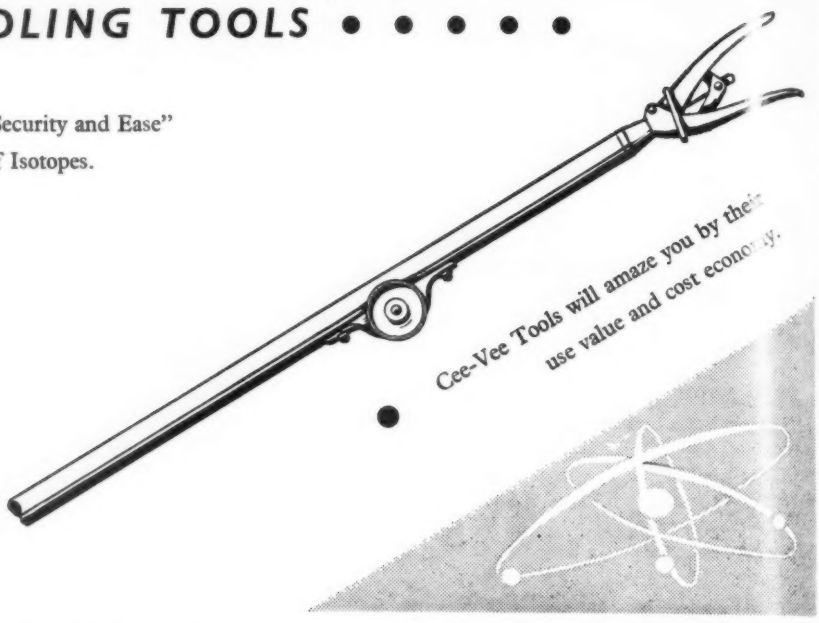

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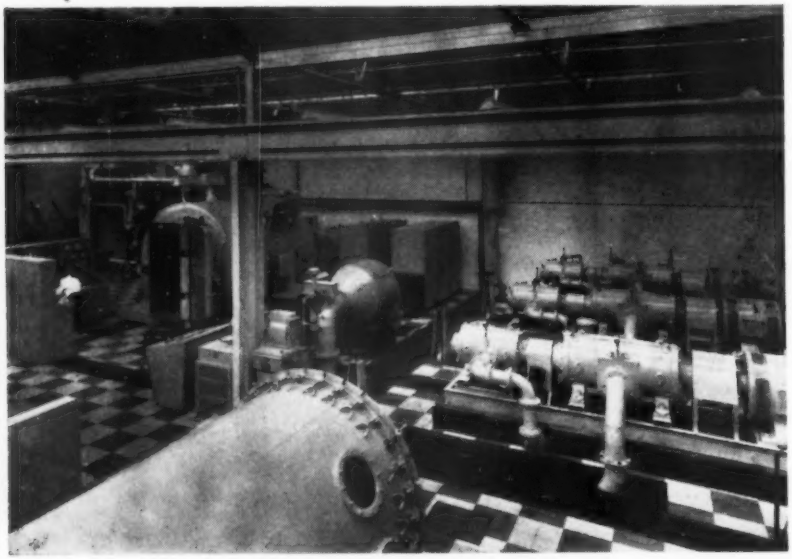

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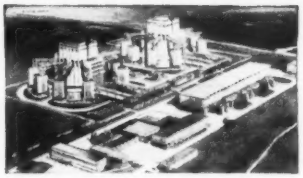

BERKELEY
(A.E.I.—John Thompson Nuclear Energy Co. Ltd.)

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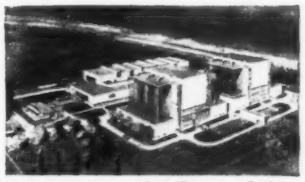
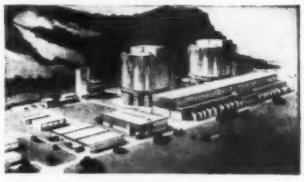


BRADWELL (The Nuclear Power Plant Company Ltd.)

fi



HUNTERSTON (G.E.C.—Simon Carves Group)

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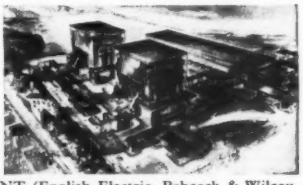

HINKLEY POINT (English Electric, Babcock & Wilcox, Taylor Woodrow Atomic Power Group)

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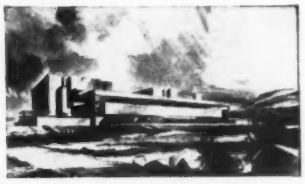

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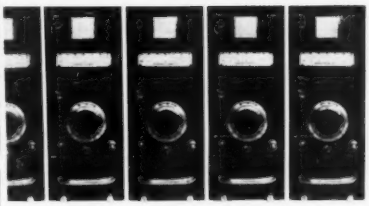

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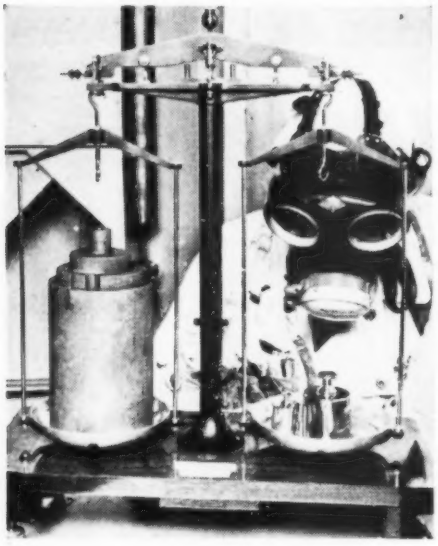

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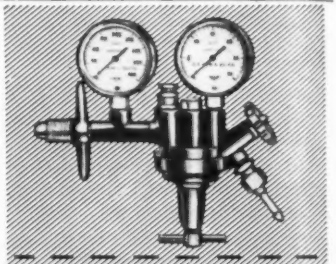

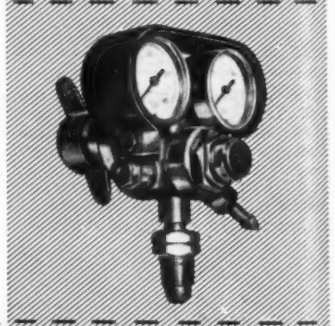

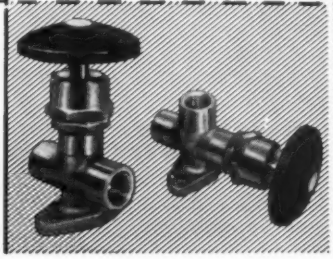

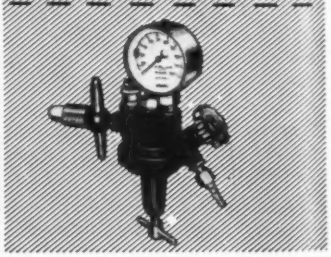

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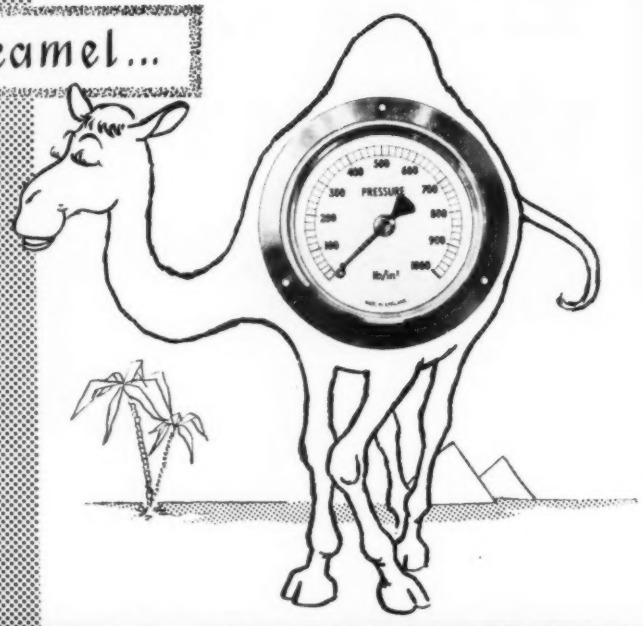

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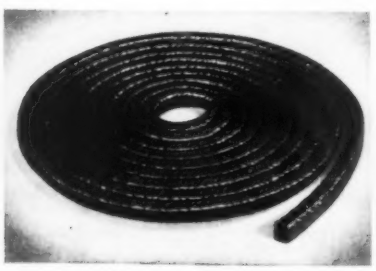

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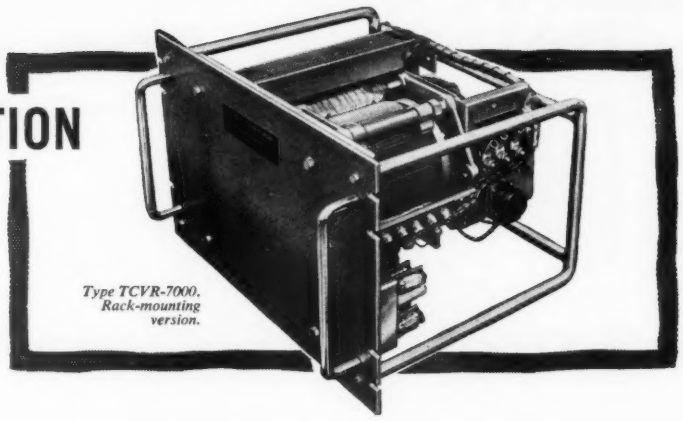

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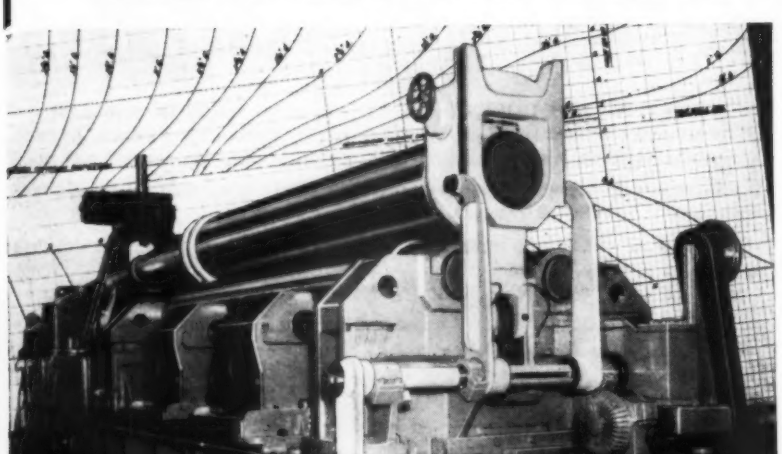

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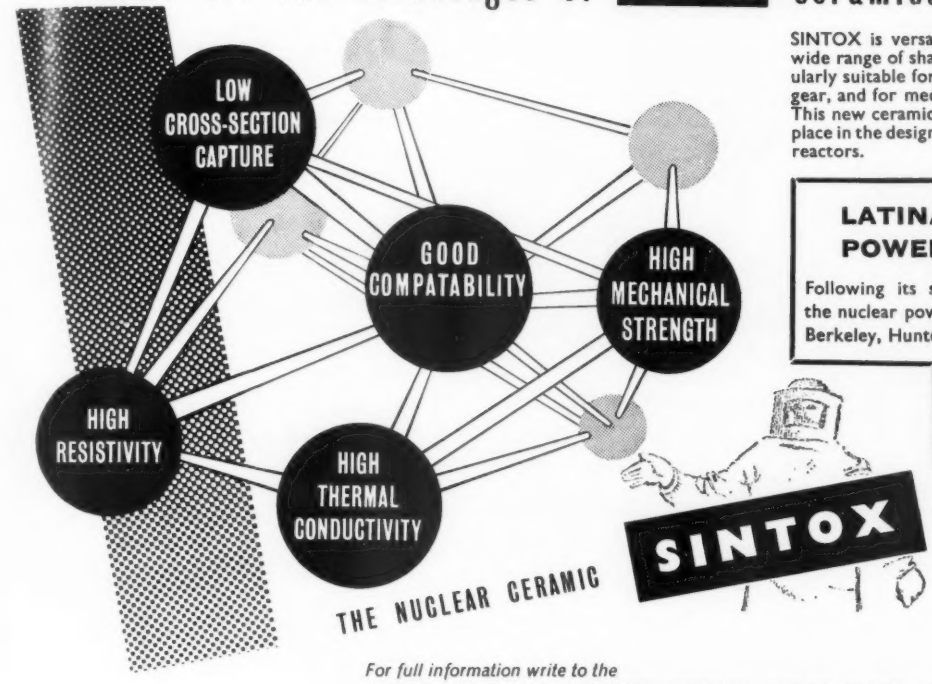

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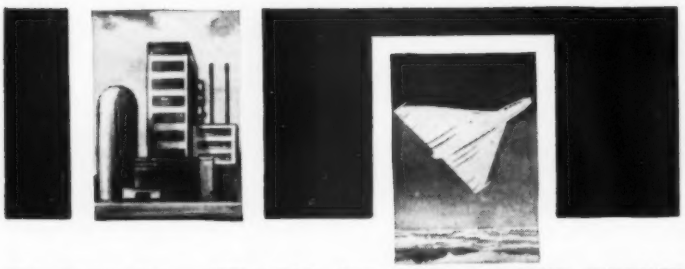

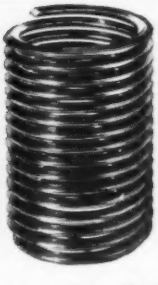

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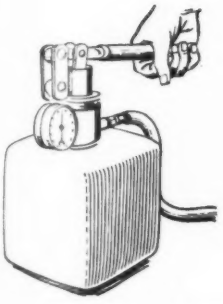

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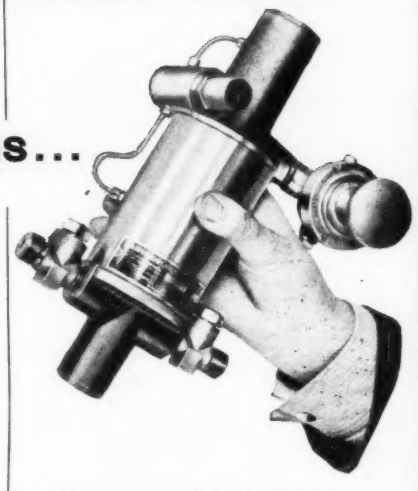
When you can use THIS...



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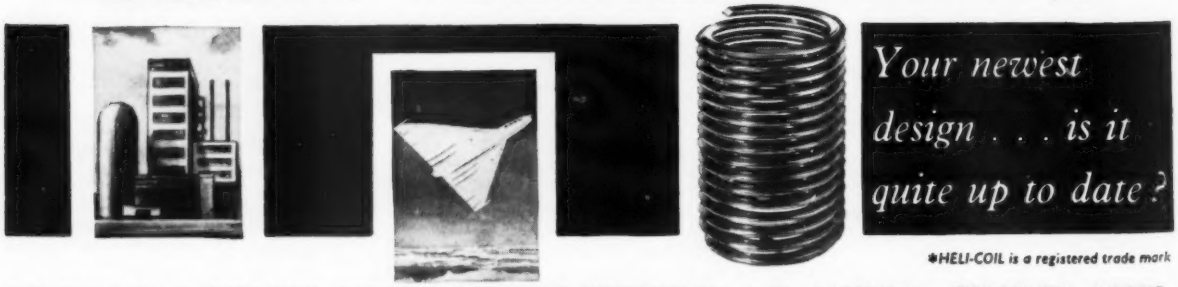

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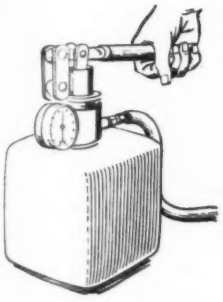

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When you can use THIS...

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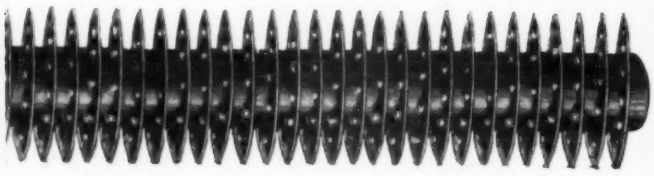

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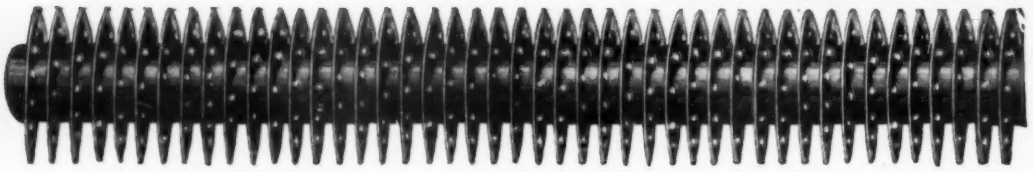

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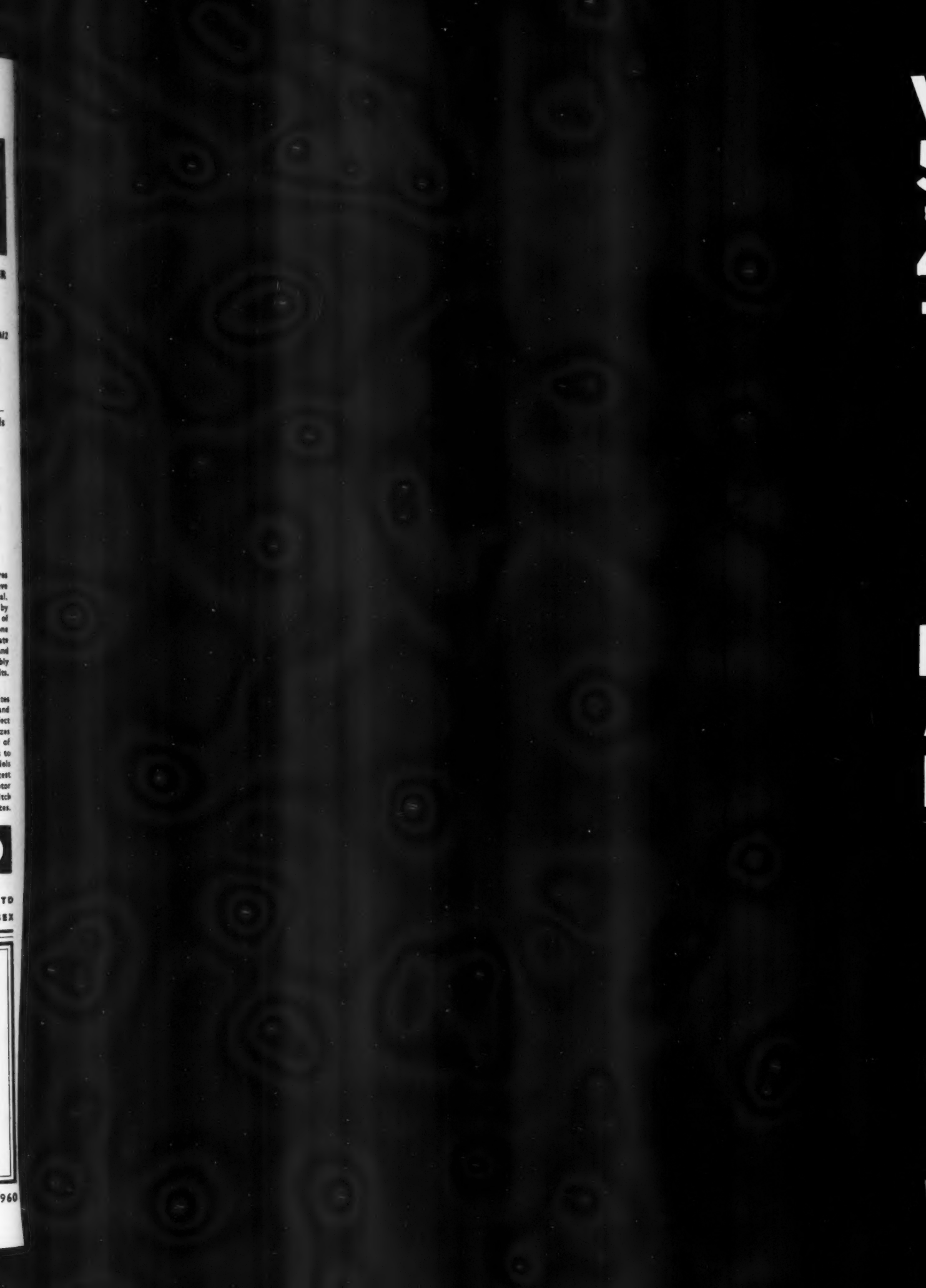

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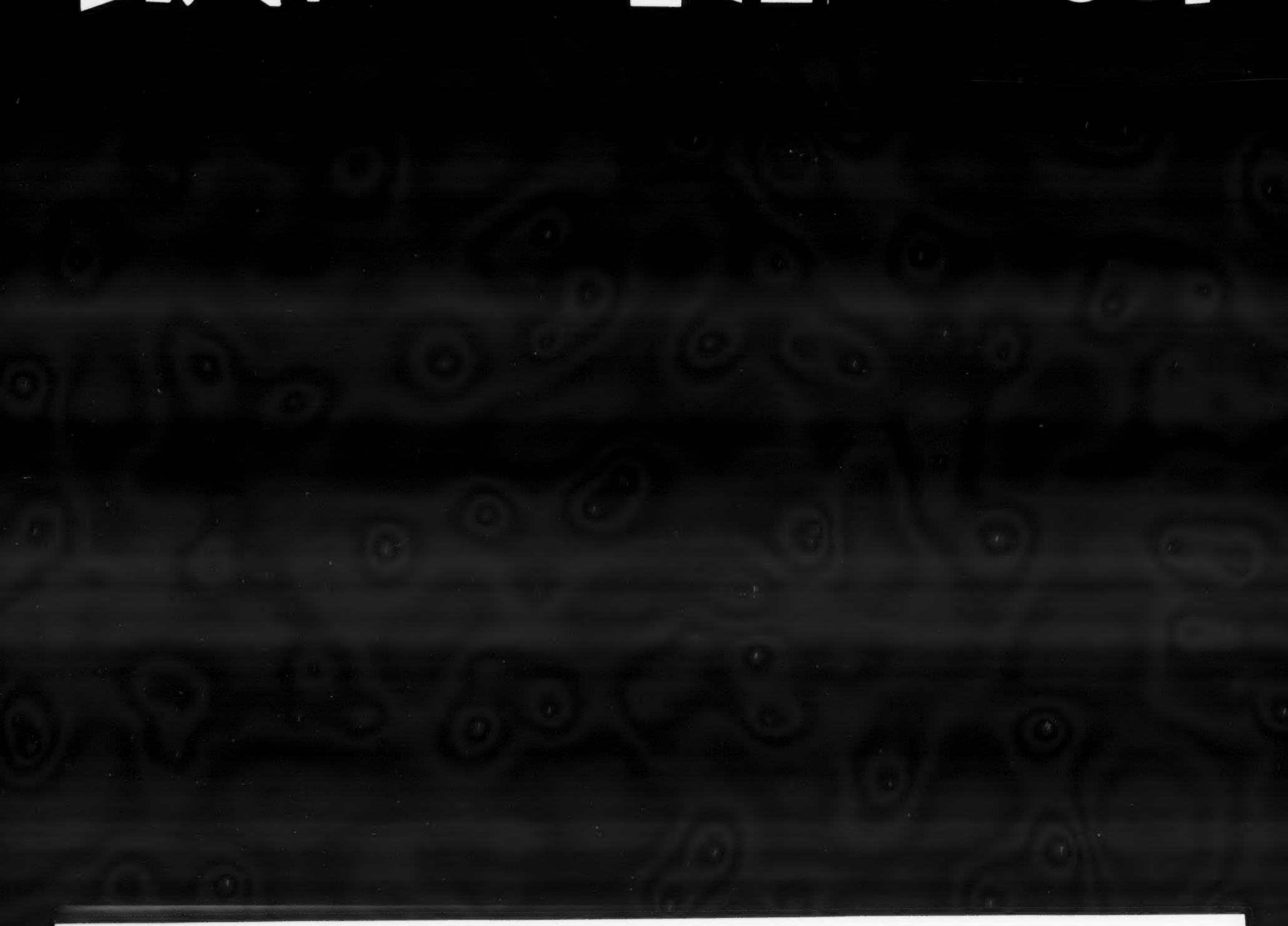

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The types of cable supplied included the Telcon 'G' range of non-microphonic co-axial cables and Balanced Twin Feeder cable with high screening efficiency, complete stability and low attenuation. Telcon also supplied Miniature Multicore co-axial cable for control circuitry. Teleconnectors (precision-made co-axial plugs and sockets) were also specified for use on those cables.

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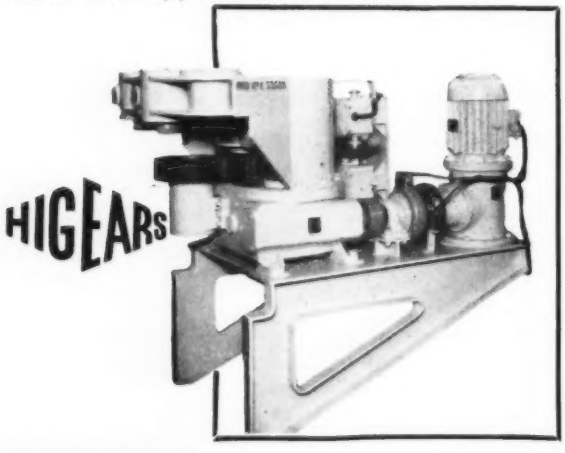

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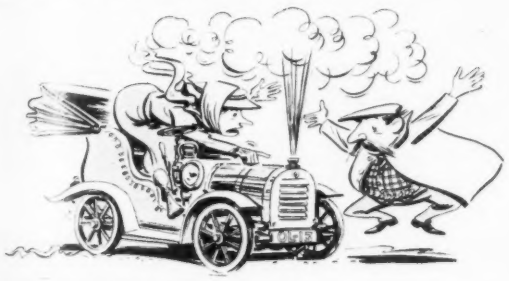

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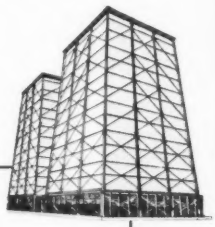

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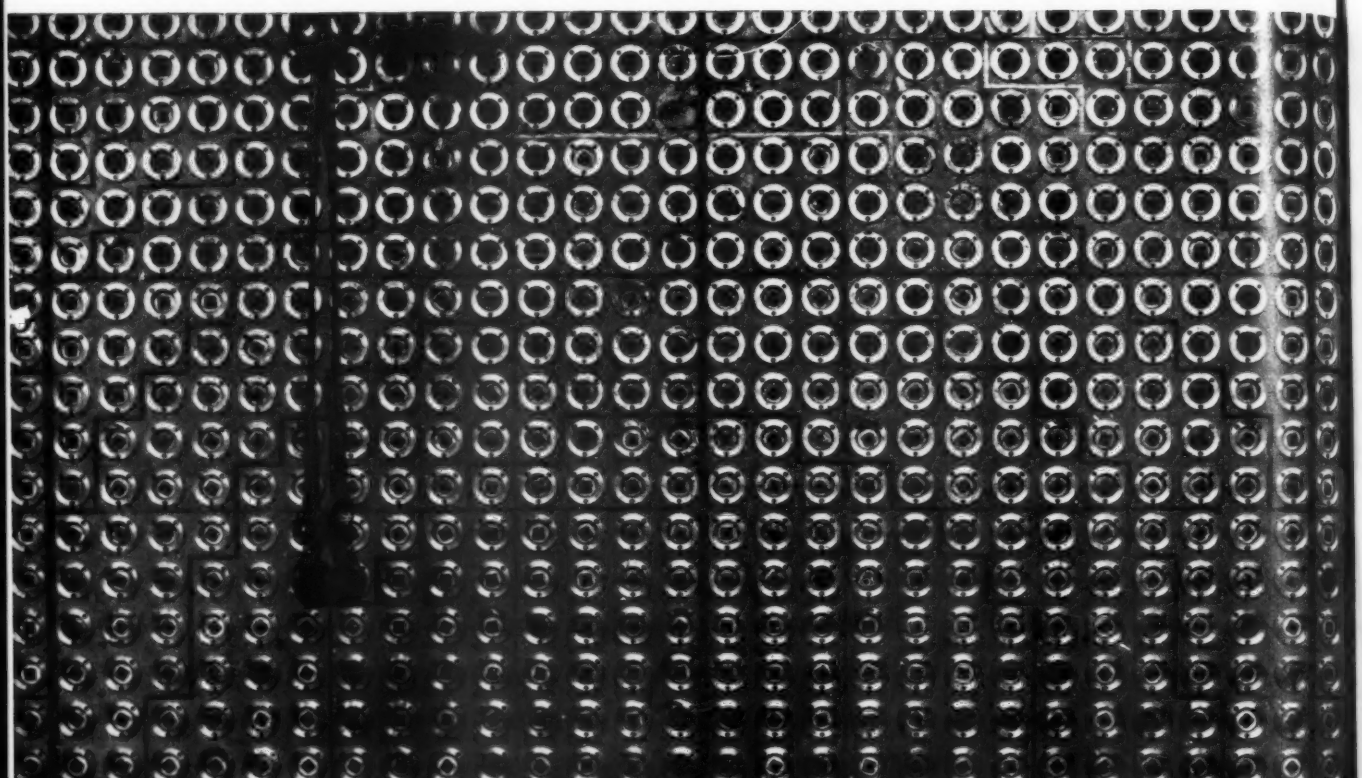

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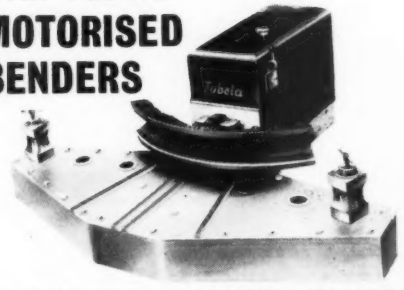

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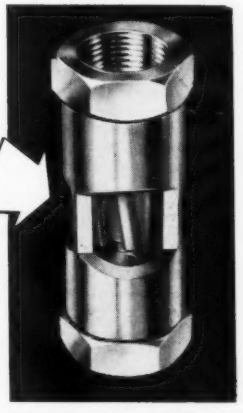

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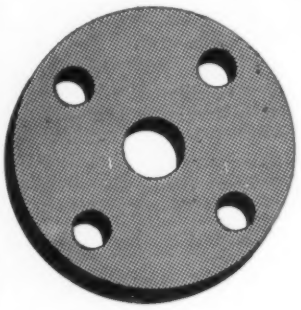

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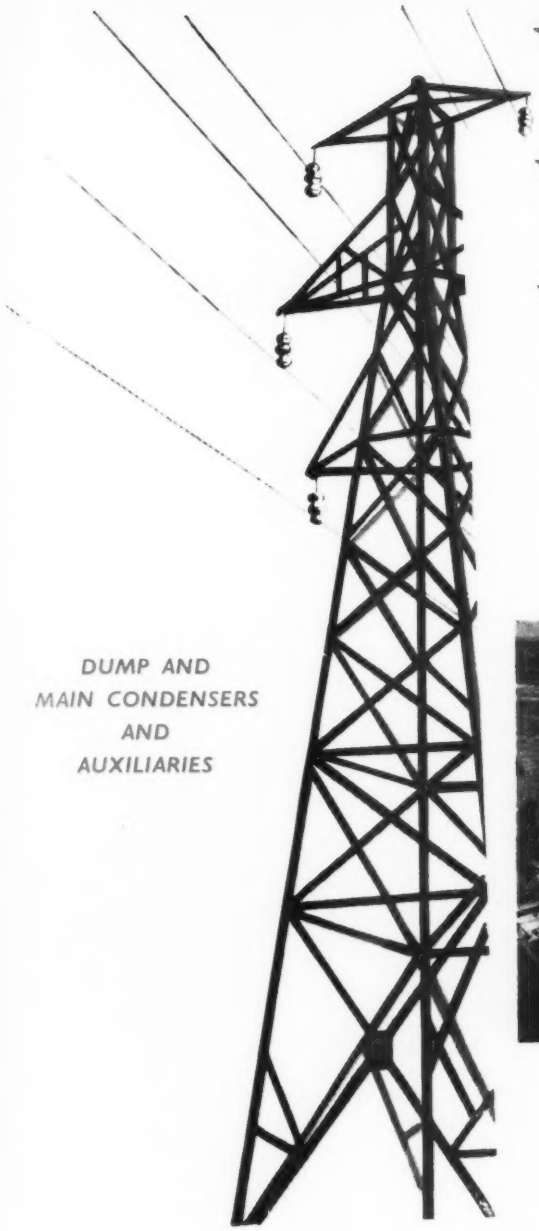

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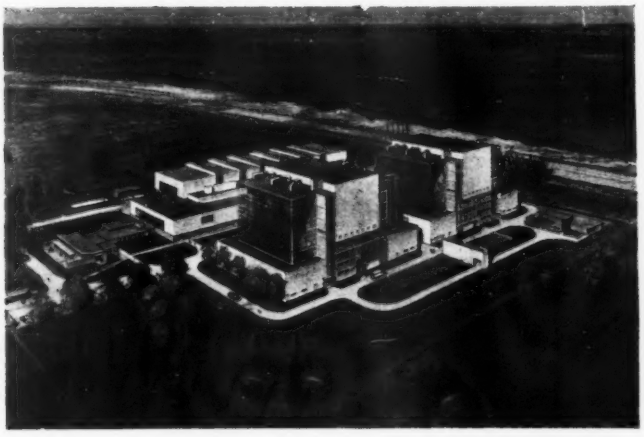

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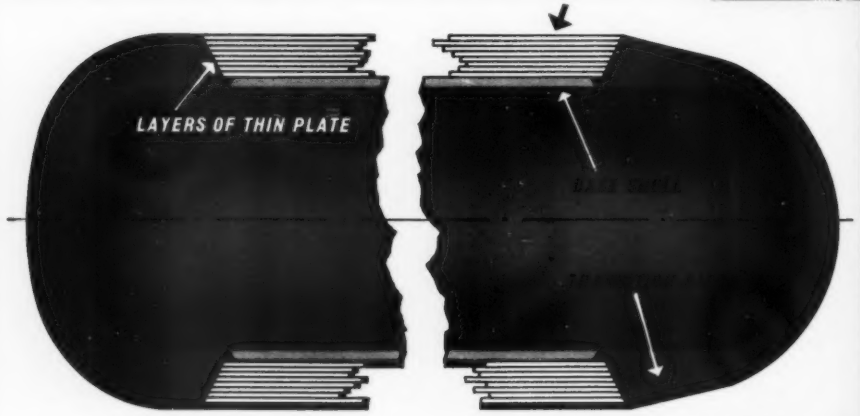

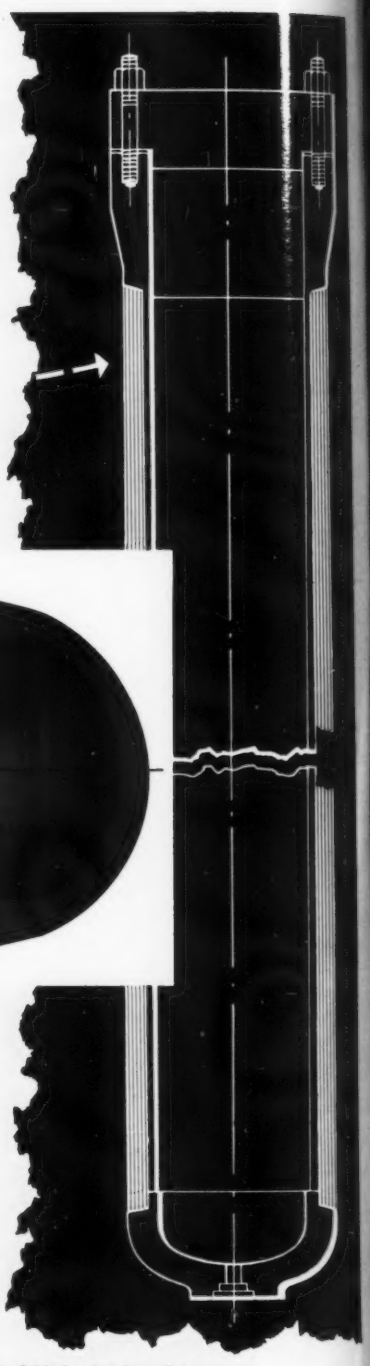

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